Application of Parametric Control Charts for Gear Cutting and Assembly Operations at TATA Engineering : A Case Study

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CERTIFICATE

It is certified that the work contained in the thesis entitled, *"Application of Parametric Control Charts for Gear Cutting and Assembly Operations at TATA Engineering: A Case Study"* by Sameer Sharma has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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ABSTRACT

Control charts used in industry at present are mostly limited to Shewhart charts (in particular X-Bar & R chart). However, these rather simplistic tools prove inadequate for certain applications which require quick detection of small shifts in the process mean. Also, it has been observed that in assembly operations the control methodology is limited to SQC (Statistical Quality Control) tools like histograms, pareto charts, cause-and-effect and check-sheets etc and, as such, usage of control charts is missing

This dissertation tries to improve upon these present practices by investigating the applicability of various control charts to the production processes For this purpose, a critique on the quality systems pertaining to the statistical process control (SPC) at Tata Engineering/Lucknow plant has been done. The complete production process has been studied in two parts. Firstly, the existing control methodology including variable control charts at the gear shop has been critically analyzed. Secondly, the possibility of applying attribute control charts to the processes in the assembly shop has been explored An analysis has been done to improve the process and as a result certain recommendations and suggestions have been arrived at

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March, 2003 Sameer Sharma

Dedicated to the Lotus feet of Lord

Venkateswara……

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LIST OF ABBREVIATIONS

Serial Number	Short Form	Full form
1.	SPC	Statistical Process Control
2	UCL	Upper Control Limit
3.	LCL	Lower Control Limit
4	USL	Upper Specification Limit
5	LSL	Lower Specification Limit
6	MSA	Measurement System Analysis
7.	Gauge R&R	Gauge Repeatability & Reproducibility
8	SQC	Statistical Quality Control
9	CUSUM	Cumulative Sum
10.	EWMA	Exponentially Weighted Moving Average
11.	TQM	Total Quality Management
12.	WECO	Western Electric Company
13.	MER	Measurement Error Ratio
14.	C_p, C_{pk}	Potential Process Capability Indices
15.	P_p, P_{pk}	Overall Process Capability Indices
16.	AD	Anderson Darling Coefficient
17.	PMPL	Parishudh Machines Private Ltd.
18.	IPG	In Process Gauge
19.	PQR	Product Quality Rating
20.	DOE	Design of Experiment
21.	FMEA	Failure Mode and Effects Analysis
22.	TE/LP	Tata Engineering/Lucknow Plant

Chapter 1

STATISTICAL PROCESS CONTROL (SPC): AN INTRODUCTION

The concept of producing any product or service revolves around three main interdependent stages: the input to the process, the process itself and the output of the process. The input could be in the form of data, material, physical labor etc; the process could be the code, guidelines, machining method etc; and output could be in the form of shape of the component, results, service obtained etc In most of the cases, these elements overlap and there is a very thin line distinguishing the two, for example, the machining method could be an element of input or the process However, for convenience the six most essential (the exact number depends upon the nature of the process and the output) elements that determine the performance of the process for the desired output are people, equipment, material, method, working environment and measurement. These elements cannot be classified as the elements of the input; instead, they are the elements of the system in totality comprising of the inputs, process and the output.

The concern of any system is the output since efforts are made to obtain the desired output but in actual sense, the word desired output in itself is some times absurd as it is not easily quantifiable and hence there exist no measure for it. In order to measure the output and to set some acceptability limits to it, it becomes necessary to derive some quantifiable parameters out of the qualitative characteristics of the output. For measuring and comparing the output, we need to first specify the limits of acceptability on the quantifiable parameters that determine the nature of the output. These become the specifications. The dependency and the interdependency of the elements of the overall system sets in some amount of variations in the output. We cannot claim for sure that

the piece coming out next will be similar to the piece rolled out just before. These variations are inherent features of any process since the concept of randomness is universal. The actual effort starts with finding out the system of causes of these variations. These could be (i) assignable cause system that is identifiable and controllable or (ii) chance cause system that are due to multiple reasons and complex, and hence cannot be identified. The variations due to chance cause system therefore are accepted as inherent to the process. The issue is then to study the nature and extent of these variations. The only resort is to scientifically collect and analyze the observations and make certain inferences about their behavior – hence application of statistical methods. The data so collected can be analyzed to estimate its central tendency (mean, median, and mode) and the spread representing the variability (range, standard deviation, and variance).

Comparing the acceptability limits for a given level of the confidence (this confidence is dictated by the user of the product or services) with the centering and the variability of the process gives us an idea of what is desired and what is finally achieved. The four essential parameters involved in the acceptability of the output [Montgomery, 1997] are:

- The centering of the process
- The variability of the process
- The precision of the measurement system
- The product specification margins

Observing and collecting data and then analyzing them for drawing out some inferences about the output and the process encompasses some statistical techniques. One of these is the control chart wherein the nature of the process and hence the output is represented by three quantities. These are upper control limit (UCL) - an alarm to indicate that the output is drifting to the positive extreme, the lower control limit (LCL) -

an alarm to indicate that the output is drifting to the negative extreme and mean value - indicating the place wherein major population of the output measured will lie. The spread between the two extremes UCL and LCL, when compared to the extremes of the specifications that are upper and lower specification limits (USL and LSL), measures the capability of the complete process. This capability is in fact the potential process capability (refer section 2.4).

On the other hand the precision of the measurement system is monitored by the measurement system analysis (MSA) since the element of randomness exists in the measuring equipments as well (refer section 2.2). Evaluating the potential process capability indices and gauge R&R ratio helps in predicting the nature of the process [Persijn and Nuland, 1996]

Making observations, collecting data, analyzing them, drawing out the inferences and then taking actions for obtaining the desired output by controlling the process briefly explains the concept of statistical process control. Thus, SPC is a comprehensive set of statistical techniques that are applied, in order to control the process and hence involves controlling elements of the complete system and their interaction.

1.1 Brief history of SPC

Statistical process control (SPC), a major area of the statistical quality control, came into existence in 1924 when Walter A. Shewhart of the Bell Telephone Laboratories developed the statistical control chart concept. This is often considered the formal beginning of statistical quality control. Later in 1931, Shewhart published a book on statistical quality control that bore the title “Economic Control of Quality of Manufactured Product” thus opening new gates to the application of control charts and related concepts in the Industry [Duncan, 1965].

In 1932, the concept traveled to Britain with Shewhart, but welcomed with a moderate response. Then in 1940, the U.S. war department published a guide for using control charts to analyze process data By 1946, more than 15 quality societies were formed in North America that floated training courses on SQC. The war-devastated Japan invited Deming to help in rebuilding Japanese industry. The year 1950 saw wide exposure of statistical quality control to Japanese industrial managers by Deming. When the Americans were busy developing new methods of production Japanese were improving their product quality by applying the SQC tools

With subsequent improvements, the British statistician introduced the cumulative sum (CUSUM) control chart in 1954; by 1959, S. Roberts had come up with a much-improved exponentially weighted moving average (EWMA) control chart. Later all these concepts were covered under the umbrella concept of total quality management (TQM) [Montgomery, 1997].

1.2 Purpose of the thesis & problem statement

It has been observed that the implementation of the statistical process control concepts, which have developed over a period of time since Shewhart charts, in industry, is difficult and hence the industry is limited to utilizing only a certain portion of it. Mostly the approach is to adopt newer concepts because that is the demand of the day and not much thought is poured into assessing the applicability and utilization of these concepts in controlling the processes. The purpose of the thesis is firstly to review the developments till date in the field of statistical process control; secondly to study the in place quality systems at Tata Engineering/Lucknow plant for the process control, and finally, critically analyzing the processes for improvements and suggesting better ways of implementing relevant process control concepts. The TE/LP is taken specifically

assuming that most of the automobile manufacturing units are represented by it although they may vary slightly.

The problem is to study the existing quality systems for process control and find out the control techniques and tools employed by TE/LP to assure the desired level of quality at various stages of the production, related to both manufacturing and assembly. Then these techniques are to be critically analyzed from the applicability, usage and the desired control point of view. The effectiveness and efficiency of the existing quality system has been evaluated subjectively (no model has been developed for the same) and genuine attempts have been made to provide with all necessary information and methodologies for improving these techniques in the existing environment

1.3 Research progression plan

The main focus of this research is the in-process control techniques and in-process inspection; as a result, the primary inspection and acceptance sampling part of the bought-out components have been done away with, but mention of these in the thesis is as and where required.

The study for the thesis has been conducted in two specific areas of the TE/LP. First, is the gear shop and second is the assembly shop The first shop is mostly involved with machining of gears on the Parishudh gear cutting machines and the second shop is assembling the regular vehicle models.

Since the gear shop is involved with the gear cutting, hence it involves many variable type characteristics on a single component (say 3rd gear). Here the study dealt with is of control charts for variable type characteristics. On the other hand, the assembly shop involves control of attribute type characteristics and hence the attribute control charts and some simple process control techniques have been covered in this shop. The research is divided in three phases as follows:

1 Literature review.

2 Process study and experimentation at gear shop

3 Process study and experimentation at assembly shop.

The literature review has been conducted to gather all the relevant information for the better understanding of the process and experiment. During this phase, special emphasis has been put on the practical application of the evolved process control concepts and techniques in the industry The second and the third phase, as mentioned, have been to draw out the complete process and critically review the applicability of these concepts in the production environment of the TE/LP.

1.4 Experimentation and recommendation methodology

The methodology of study at the work area is divided into three main categories:

1. As is analysis
2. Gap analysis
3. Recommendations and comments

1.4.1 *As is* analysis

As is analysis is done to answer the following questions:

- What is expected out of the process control system?
- How does the process control system achieve it?
- What level of control is actually achieved by the existing system?

Answering the above three queries required in-depth review of the current systems of the shops for process control and, since the focus of the experiment is on statistical techniques, the analysis is done to capture all information related to it. Hence as is analysis includes the study of the current control charts, sampling details, type of control

charts employed, number of shifts and their details, defect detection, inspection and their stages, number of inspectors, level of control required, process improvement techniques etc

1.4.2 *Gap* analysis

The gap analysis is done after finding out the answers to the questions such as how does the system achieve and to what level. Basically, this is done to know exactly where are the gaps in the existing system that need to be filled in order to match the achieved level of control to the expected It focuses mainly on those areas that can lead to an increase in the effectiveness and efficiency of the existing process control methodology.

1.4.3 Recommendations and comments

Once the gap analysis indicates the gaps in the existing system for the quality control, an attempt is made to bridge these gaps by the current and improved tools for the statistical process control and is mostly in the form of recommendations and comments. Mostly these recommendations are based on the field observation and have been given where it is felt that the existing practice could be further improved by taking the inputs from the literature review. An attempt has been made to incorporate the most effective way for improving the existing practices

1.5 Outline of the thesis

The complete thesis is divided into five chapters. The first chapter gives a brief account of the statistical process control (SPC) and its evolution Apart from this, the purpose and the problem have been defined The progression plan indicating the course of the

complete study for the thesis along with the methodology for two experiments conducted has also been explained

The second chapter pinpoints and explains the most relevant concepts of SPC from the point of view of the thesis. These concepts help in choosing the correct control charts for various processes and analyzing them in the most efficient way. A simple but efficient flow chart for process improvement has also been explained.

The third chapter is a summary of the process study and experiment conducted at the gear shop The details of the process capability study conducted and the results obtained have been explained. Based on the observations and the results, recommendations have been given.

The fourth chapter is a summary of the process study and experiment conducted at the assembly shop. Here the focus has been on the possibility of implementing the attribute control charts on the assembly line. The actual defect data has been plotted for the frequency distribution and compared to the probability mass function of the Poisson distribution. Based on the results obtained, the control charts have been designed and the demerit system (Montgomery, 1997) has been explained.

The last chapter concludes the thesis with a brief summary of the analysis and recommendations. The possibilities of further research have also been explored.

Chapter 2

LITERATURE REVIEW

2.1 Control charts

Problem in choosing a control chart and analyzing it is a major task The most favored and popular methodology for selecting a chart and then analyzing it for out of control situations is as follows

2.1.1 Guidelines for the design of the control chart

The main reason for using the control charts is that we want to predict the behavior of the process based on some parameters that have been calculated for it. We need control charts since 100% inspection is a resource consuming exercise. In some cases 100%, inspection is not possible like the case of destructive testing. To avoid 100% inspection samples are drawn and inspected. Based on the observations for these samples some inferences are made which predict the nature of the population to a great extent Thus, the control charts act as bounds for the population and for designing any control chart we need to specify the following three things.

1. Sample size
2. Control limit width
3. Frequency of sampling

If the X bar & R chart is being used primarily to detect moderate to large process shifts, say on the order of 2σ (σ here denotes standard deviation a measure of variability) or larger, then relatively small samples of size n = 4, 5 or 6 are reasonably effective. On the other hand if, if we are trying to detect small shifts, then larger sample sizes of possibly n = 15 to 25 are needed. When smaller samples are used, there is less risk of process shift occurring while the sample is taken. If a shift does occur while a sample is taken, the sample average will obscure this effect. Consequently, this is an argument for using

as small a sample size as is consistent with the magnitude of the process shift that one is trying to detect. An alternative to increasing the sample size is to use the warning limits and other sensitizing procedures to enhance the ability of the control chart to detect small process shifts. However, this is not desirable and if small shifts are of interest then CUSUM or EWMA charts should be used (refer Fig 2.1).

An EWMA (Exponentially Weighted Moving Average) Chart is used when it is desirable to detect out-of-control situations very quickly. EWMA charts have a built in mechanism for incorporating information from all previous subgroups and weighing the information from the closest subgroup with a higher weight. Thus, the control/out-of-control decision is made with information from previous subgroups as well as the current subgroup. The chief advantage of EWMA charts is that they detect out-of-control conditions more quickly than X-bar charts and that using only one rule being within or outside the 3σ limits can do this detection The chief disadvantage is the EWMA chart is that it is more difficult to construct.

In situations where the normality assumption is violated to a slight or moderate degree Shewhart control charts will still work reasonably well. However, as noted, for subgroup sizes of less than 4, non-normality can lead to serious problems (in particular, a high false alarm rate). Importantly, the EWMA structure is insensitive to normality (since points are moving average of the several observations and hence by central limit theorem are normally distributed), whereas CUSUM charts are sensitive to normal assumptions. This makes the EWMA chart an attractive candidate in general when addressing small changes in a process.

If the EWMA chart is to be used for smaller shifts then the value of weight (λ) is taken to be small (<0.2) but if it is to be used to detect moderate to large shifts then the λ value is taken large (0.2<λ<0.4). It is to be noted that the EWMA chart with λ=1 is an X-Bar chart.

The use of 3σ control limits on the X-bar and R control charts is a widespread practice since it is most cost effective and covers 99.73% of the population values. There are situations, however, when departures from this customary choice of control limits are helpful For example, if false alarms or type I errors (an out of control signal is generated when the process is really in control) are very expensive to investigate, then it may be best to use wider control limits then 3σ perhaps as wide as 3.5σ. However, if the process is such that out-of-control signals are investigated quickly and easily with a minimum of lost time and cost, then narrower control limits, perhaps at 2.5σ, are appropriate [Montgomery, 1997]. Now days where the quality is foremost and the cost takes the back seat the concept of 6σ has emerged. The main aim of the concept is to make the process capable enough so that the total spread of 12σ can be accommodated within the specification limits.

Flow chart of figure 2.1 helps in choosing the relevant control chart.

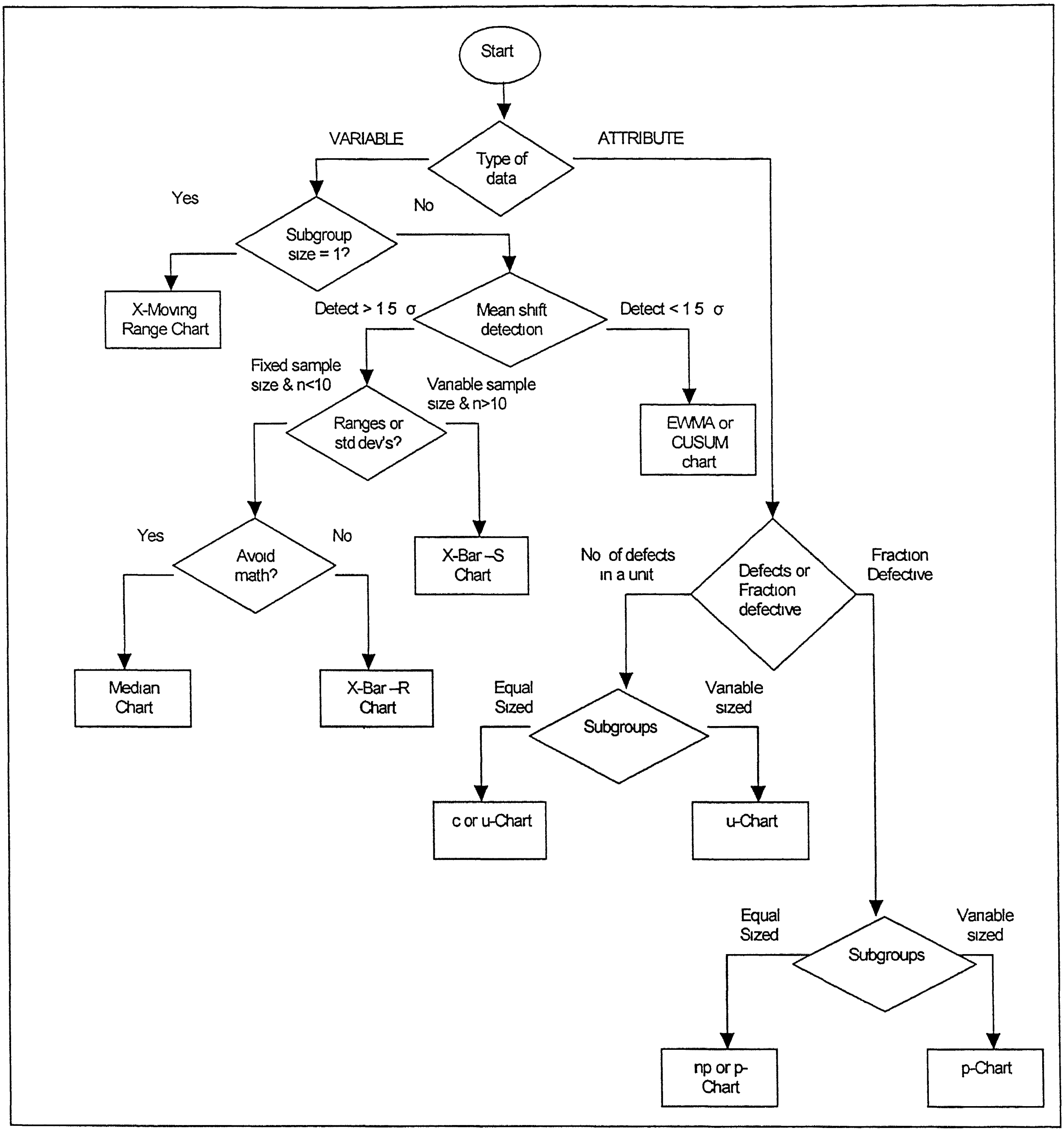

Fig. 2.1: Flow chart for control chart selection
[Adapted from Sytsma et al , 2003]

2.1.2 WECO (Western Electric Company) rules

General rules for detecting out of control or non-random situations of Shewhart charts are, any point above +3σ, 2 out of the last 3 points above +2σ, 4 out of the last 5 points above +1σ, 8 consecutive points on any one side of control line, 4 out of the last 5 points below - 1σ, 2 out of the last 3 points below -2σ, any point below -3 σ and 6 in a row trending up or down or 14 in a row alternating up and down.

The WECO (Western Electric Company) rules are based on probability. We know that, for a normal distribution, the probability of encountering a point outside ± 3σ is 0.3% This is a rare event Therefore, if we observe a point is outside the control limits, we conclude the process has shifted and has become unstable. Similarly, we can identify other events that are equally rare and use them as flags for instability. The probability of observing two points out of three in a row between 2σ and 3σ and the probability of observing four points out of five in a row between 1σ and 2σ are also about 0.3%.

While the WECO rules increase Shewhart chart sensitivity to trends or drifts in the mean, there is a severe downside to adding the WECO rules to an ordinary Shewhart control chart that the user should understand. When following the standard Shewhart "out of control" rule (i e , signal if and only if you see a point beyond the plus or minus 3 sigma control limits) you will have "false alarms" every 371 points on the average (1/p=1/0 0027). Adding the WECO rules increases the frequency of false alarms to about once in every 91.75 points, on the average. The user has to decide whether this price is worth paying (some users add the WECO rules, but take them "less seriously" in terms of the effort put into troubleshooting activities when out of control signals occur) [NIST/SEMATECH].

2.2 Measurement system analysis (MSA)

Before measuring the characteristics for the variation and the process capability analysis it is mandatory to know the capability of the measurement system or else its variation will account for the most of the variations in the process. Gauging capability is assessed by measurement error ratio (MER) a preliminary examination and if the gauge does qualify, then gauge R&R statistics are calculated for detailed analysis.

2.2.1 Measurement error ratio (MER)

As a preliminary examination of the gauge, the concept of MER is applied; this then helps in determining whether further analysis is required or not. MER is the ratio of the standard deviation of the 25 measurements taken to the total tolerance. *If the MER is less than 0.10, the gauging is adequate. If the MER is between 0.10 and 0.15, the gauging and method should be tested further In addition, If the MER is greater than 0.15, the gauge should be tested and altered to reduce measurement error* [Floyd and Laurent, 1995].

2.2.2 Gauge repeatability and reproducibility

The gauge R&R statistics can be calculated by completing the standard Long form of general motors [Floyd and Laurent, 1995]. The output will be a percentage that relates the repeatability, reproducibility, and overall R&R to the specification range that the gauging technique requires. *It is an industry standard that a gauge requiring less than 10% of the specification range is unconditionally accepted, one that requires 10-20% is conditionally accepted, one that requires 20-30% is conditionally rejected, and one that requires more then 30% of the specification range is unconditionally rejected.* If the gauge falls between 10% and 30%, the customer should be consulted to discuss the

gauging. Possible corrective actions include (1) reworking the gauge (2) further training of the operator (3) use of another measurement methodology.

When analyzing the corrective action required for the gauge, the overall R&R statistic is used to determine acceptability. The individual repeatability and reproducibility statistics will indicate the area on which to concentrate. If the repeatability statistic is high, problem likely resides in the gauge itself; therefore, the gauge should be evaluated for design and structural integrity. A high reproducibility statistic indicates a high level of variation between individual operators, and training should be the focus of improvement activity [Floyd and Laurent, 1995].

2.3 Selection of subgroups based on the order of production

Where order of production is used as a basis for sub grouping, two fundamentally different approaches are possible:

1. The first subgroup consists of all products that are produced as nearly as possible at one time; the next subgroup consists of all products that are produced as nearly as possible at a later time, and so forth. For example, if the subgroup size is five, the quality control inspector who makes measurements at hourly intervals, may measure the last five items that were produced just before each hourly visit to the machine. This is possible on machine parts, for example, if the parts are placed by the operator in trays in the order of production; in other words the pieces are marked in such a way that the time dimension is maintained.

2. A subgroup taken at a particular time represents all the production over a given period of time; the next subgroup taken at another time (say after an hour) represents production of approximately the same quantity of product in a later period; and so forth. Where products accumulate at the point of production, the inspector may choose a

random sample from the entire product made since the last visit. If this is not practicable, there might be five visits (if n = 5) approximately equally spaced over a given production quantity or time with one measurement made at each visit, these five measurements constitute one subgroup

The first method helps in selecting subgroups such that the chances of variation within the subgroup are minimal but the chances of variations in between the two subgroups can easily be detected It can thus provide us with the best estimate of a value of σ that represents the ideal capabilities of a process obtainable if assignable causes of variation, from one subgroup to another, can be eliminated Moreover, it increases the sensitivity for measuring the shifts in the process average; it makes the control chart a better guide to machine setting or to other actions intended to maintain a given process average. Thus, the first method is more ideally suited for the analysis of a process and its control.

However, if sub grouping is by the first method and a change in process average takes place after one subgroup is taken and is corrected before the next subgroup, the change will not be reflected in the control chart. For this reason, the second method is sometime preferred where one of the purposes of the control chart is to influence decisions on acceptance of product [Grant and Leavenworth, 1988]

2.4 Process capability indices and analysis

Capability indices are simplified measures to describe quickly the relationship between the variability of the process and the spread of the specification limits. Like many simplified measures such as the grades A, B, C, D and F in school, capability indices do not completely describe what is happening with a process. They are useful when the assumptions for using them are met to compare the capabilities of processes.

The potential capability indices- C_p and C_{pk}

The equation for the simplest capability index, $C_{p,}$ is the ratio of the specification spread to the process spread the later represents 6 standard deviations or 6σ

$$\boxed{C_P = (USL - LSL)/6\sigma}$$

C_p assumes that the normal distribution is the correct model for the process C_p can be highly in accurate and lead to misleading conclusions about the process when the process data does not follow the normal distribution

Remember that the capability index C_p ignores the mean or target of the process If the process mean lined up exactly with one of the specification limits, half the output would be non-conforming regardless of what the value of C_p is. Thus, C_p is a measure of potential to meet specification but says little about current performance in doing so.

The major weakness in C_p is the fact that few if any processes remain centered on the process mean. Thus, to get a better measure of the current performance of a process, one must consider where the process mean is located relative to the specification limits. The index C_{pk} has been created to do exactly this. With, the location of the process center compared to the USL and LSL is included in the computations and a worst-case scenario is computed in which C_p is computed for the closest specification-limit to the process mean [Mitra, 1998].

$$\boxed{C_{Pk} = \min\{(USL - \mu)/3\sigma, (\mu - LSL)/3\sigma\}}$$

2.5 Process improvement

The flow chart in fig 2.2 is self explanatory and very handy for making the processes capable or taking various decisions on them.

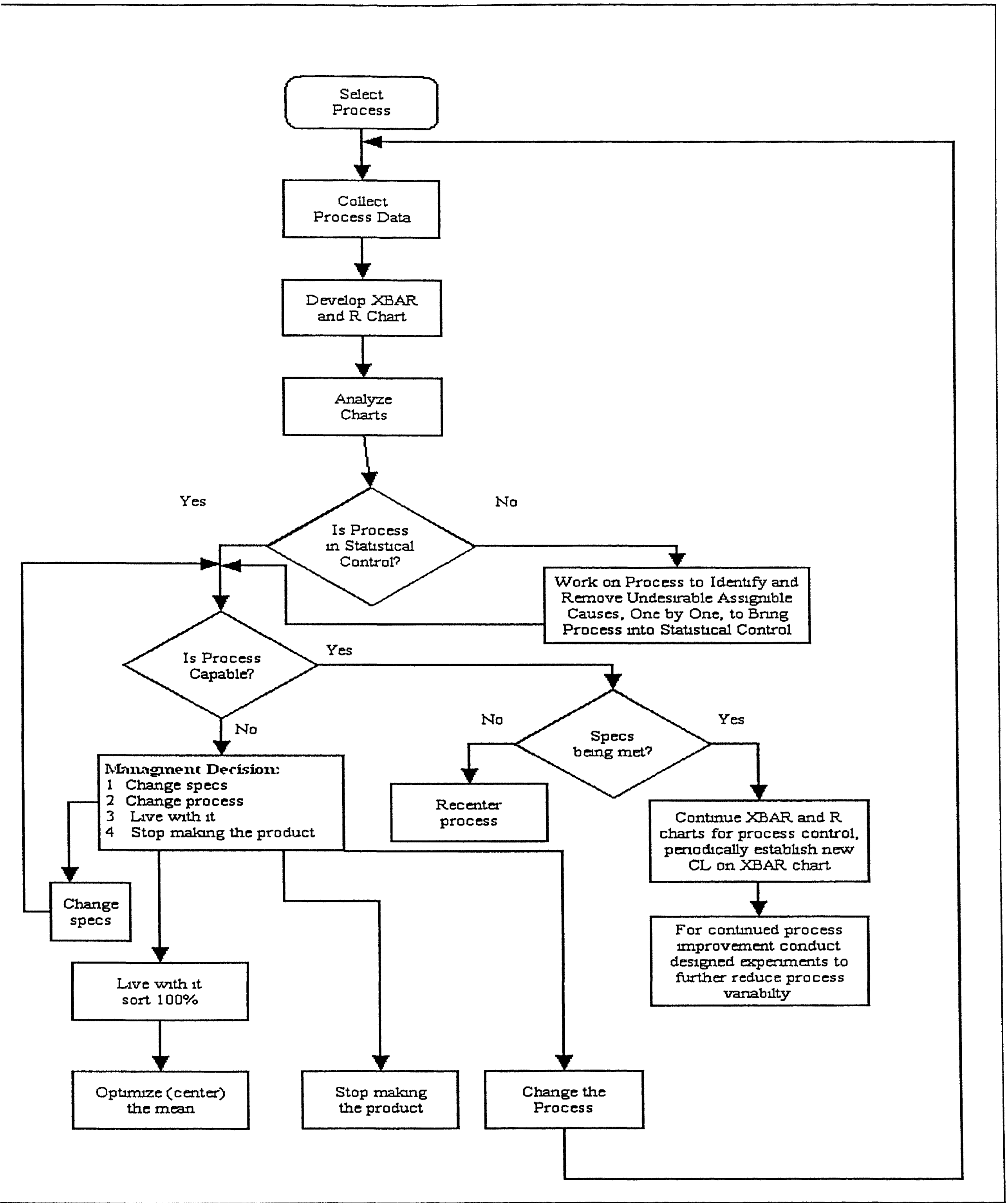

Fig. 2.2: Process improvement flowchart
[Adapted from Sytsma et al., 2003]

Chapter 3

PROCESS STUDY AND EXPERIMENTATION AT GEAR SHOP

3.1 Introduction

Gear shop has been chosen for the study since the gear shop comprises of machining line The main product of the gear shop is gear It manufactures gears for the gearboxes of popular model named Sumo SE and its variants (GBS 76) and all 407 range LCV's (GBS 18) The machines employed for this purpose are mostly Parishudh Machines Pvt Ltd (PMPL) make CNC machines The production plan is such that a particular type of gear is manufactured in a single go. That is, if 3rd gear of gearbox GBS 18 is to be manufactured than the total production of that month for that particular gear will be manufactured in a single setup Hence, for each and every gear, setting is done once a month except in few abnormal situations.

First of all the gear manufacturing process has been studied. The as is analysis has been conducted to look into the control chart design and usage practices at TE/LP The measurement system analysis methodology has also been studied. In order to get an idea of the process behavior an experiment has been conducted wherein the capability study on the most critical machine has been done. The cause and effect analysis for identifying the assignable causes have also been done for the various defect opportunities. Finally, based on the observations, recommendations have been given.

3.2 Process study

The production process at gear shop mainly relates to the production of speed gears The process flowchart and other details of the process are given below. The gear

manufacturing process is a seven-stage process (refer Fig 3.1). The seven stages are described below

Incoming inspection: The semi-finished gears are received from the vendor. These are sampled as per acceptance sampling norms and then primary inspection takes place. If the lot is acceptable, it is forwarded to the next stage and if it is not acceptable then either it is returned to the vendor for the rework or it is scrapped in the shop.

Shaving: Gear shaving process is an accepted method for producing accurate gears. It is performed after the teeth have been generated by hobbing, shaping or broaching methods (which are being done by the supplier), the shaving process removes small amounts of material from the gear tooth profiles to provide high quality gears with excellent surface finish characteristics. The shaving makes the good and better gears.

The gear shaving process can be applied to involute external or internal gears having either spur or helical teeth. Shaving results in producing accurate profiles, tooth spacing, helix angle and improved surface finish. There are two basic methods of shaving external spur or helical gears. One uses a serrated tooth rotary tool in the form of a helical gear and the other serrated tooth tool in the form of a rack. Internal spur or helical gears are shaved by rotary shaving method.

Rotary shaving is accomplished by a shaving cutter that has the same normal diametric pitch and normal pressure angle as the gear being shaved. The helix angle of the cutter normally differs from that of the work gear by 5 degrees to 18 degrees. The work and cutter gears are rotated in tight mesh under pressure with a relatively slow feed per revolution. Axial sliding between the mating teeth resulting from the crossed axes relationship of the cutter and work gear causes the edges of the serrated cutter profiles to remove small amounts of stock from the work gear in the form of curled hair like chips. Shaving of the full face is accomplished by either the work gear or the cutter. Rotation of the cutter in mesh with the cutter is accomplished by driving either the work or the cutter.

The teeth may be shaved to a constant tooth thickness (straight) by the rotary shaving process, they may be made to taper by tilting the cutter or work gear. Crowned gear teeth in which the teeth are thinner at ends then in the middle can be accomplished either by rocking the work gear during the shaving operation or by using a cutter with reversed crowned teeth

Here 40 micron of material is shaved off on both sides of the teeth. This is a very critical operation hence it is done in-house

Heat treatment: After shaving operation, the gears are sent to Heat treatment shop. Heat treatment is done for the surface hardening of the gear teeth. This process is an eleven-stage process The stages are as given below.

Endo gas generation: The liquefied petroleum gas (LPG) is passed to the Endo gas generator where it gets cracked The cracked output is then mixed with the LPG and is passed on to the furnace.

Pre-washing: The components before being loaded on to the furnace are pre-washed in the two-zone washing machine in order to remove dirt and rust. Firstly, the components are degreased and then are water washed with a slight alkaline solution.

Loading: The components before being loaded are assured to be free from burrs, dirt, grease etc. Loading is done to the rated capacity of the furnace.

Pre-heating: The components loaded in the furnace are pre-heated at the temperature of 450° centigrade for about 60 minutes and the required pressure is maintained in the furnace.

Carburizing: Carburizing takes place in two stages, which are not physically distinguishable. The first stage is active carburizing where in the carbon potential and temperature are maintained at 1% and 930° centigrade respectively. The complete cycle is of 60 minutes. The second stage is diffusion; here the carbon potential and

temperature are maintained at 0.9% and 930° centigrade respectively. The complete cycle is of 30 minutes.

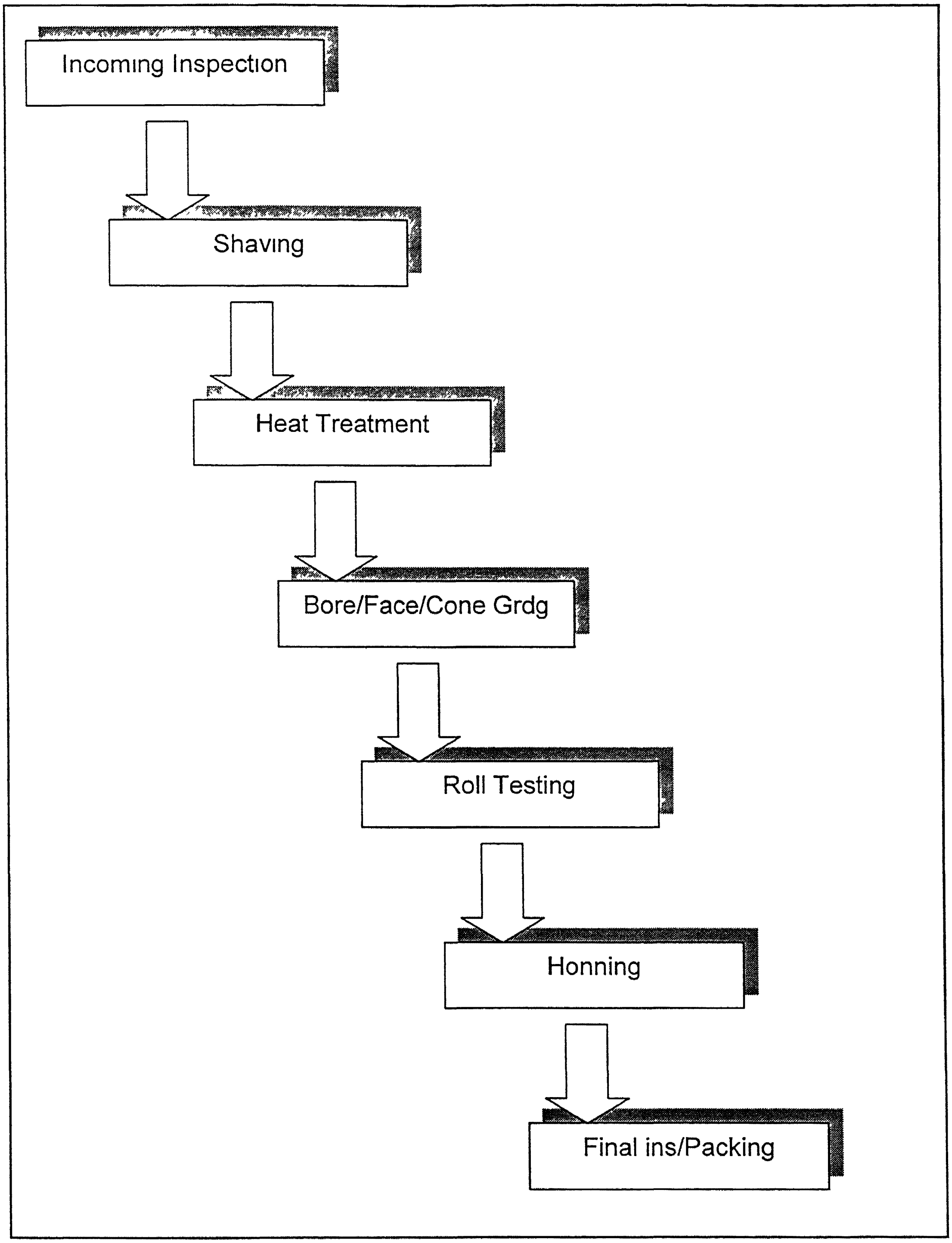

Fig. 3.1: Process flow diagram of gear shop

Intercooling: The carburized components are then cooled down to 500°-650° centigrade in the intercooler in order to relieve the stresses developed during carburizing and to avoid the retained austenites which in turn get corrected to globular carbides. The complete cycle time is 60 minutes.

Hardening: After intercooling, hardening is done at 840° centigrade at 0.9% carbon potential set point. The cycle time at this stage is 120 minutes.

Quenching The hardened components are oil quenched at 80° centigrade for 15 minutes

Post-washing: The components are cleaned, degreased and washed in alkaline solution to remove the traces of quenching oil

Tempering: The residual stresses are removed by tempering at 180° centigrade for 120 minutes.

Shot blasting: Lastly, the heat-treated components are shot blasted to remove the traces of the surface stresses.

Bore/face/cone grinding: After heat treatment the critical dimensions bore diameter, gear width, cone diameter, cone angle and ungrounded face run out are machined by a PMPL CNC internal grinding machine. This is the major machining station since a single machine is machining almost all the critical dimensions. The experiment has been conducted on this machine.

Machine consists of two axis controlled by Sinumerik 810 CNC system. On the X-axis, external grinding head and internal grinding head are mounted. On Z-axis, work head and dresser for the internal as well as external grinding wheels are mounted. Work head is driven by an AC servomotor, which gives variable speed as per component's requirement between 30 rpm to 650 rpm. X-axis is driven by Seimens 12 NM servomotor and has encoder feedback. Z-axis is driven by 8 NM servomotor and also has encoder feedback

Machine is tooled with ITW double diaphragm chuck with interchangeable cassettes for grinding of multiple bore, front and back faces and internal cone diameter of gear type components in single chucking. Double diaphragm chuck can be converted into single diaphragm chuck for all single components Machine is also tooled up with BKL expanding collect for grinding of internal taper cone and external shoulder of shifter sleeves in single setup.

The wheels are dressed once during one grinding cycle. The wheel is changed after it reaches a minimum allowable diameter. The number of components, which a wheel can grind, changes with the job size The number of components that can be ground by a wheel also depends upon the reduction of the wheel diameter in one job cycle. For example, during face grinding of one speed gear there is a reduction in wheel size by 50 microns. The new wheel diameter (after initial dressing) is 32.8 mm while the minimum allowable wheel diameter is 27.5 mm. Thus net reduction in wheel size is 5.3 mm. so the number of jobs ground by a wheel are (5300/50) equal to 106 components.

Roll testing: Roll testing is an actual condition simulation test wherein the manufactured gear is engaged with the master gear without any run out and then rolled. There is a gauge, which reads the combined run out, which is actually the run out of the manufactured piece. This is being done on every 5^{th} piece manufactured. The allowed run out of the complete setup is 50 micron

Honing: It is the last operation, which is being done to give desired finish to the bore surface. The honing operation removes 4 micron and hence increases the bore diameter by same amount

Final inspection/packing: After honing, the finished and complete gear is sent for the final inspection and then packing The final inspection is based on the sampling and only visual inspection is done on 100% pieces. The gears are manufactured for the spares as well as for in house consumption.

3.3 Experimentation and analysis

The experiment has been conducted and as is along with the gap analysis has been done. The recommendations based on these have also been given.

3.3.1 *As is* analysis at the gear shop

The main or rather the only control chart as such employed for the machining processes that could be seen through out the shop is X- Bar R chart. As a standard practice, the construction of the control chart involves the following steps:

1. In all minimum 25 subgroups are taken for data grouping
2. Sample size of 5 is taken to capture inherent variation sufficiently with exceptions in few cases.
3. Range control chart is constructed.
4. If from the range plot, it is observed that the data is not homogenized, the points outside the range are eliminated.
5. The above process is repeated till the homogenized data is obtained and the points eliminated did not exceed the 15% of the total plotted points.
6. R chart is revised.
7. If the process is not stable even after the homogenization, the sources of variations for instability are identified and corrected. Fresh data set is taken and the above steps repeated.

The standard process control procedure sheet for the shop asks for calculating standard deviation σ and then its confidence bounds based on the chi square at 95 % confidence interval but in actual practice the shop in-charge is not considering the variability in the estimate of the standard deviation for the estimation of the potential process capability indices C_p, C_{pk} bounds.

Once the readings are obtained these are utilized for constructing the histogram and following questions are asked:

- Does the overall average lie in the group having maximum frequency?
- Is there a gradual decreasing trend in the frequency on both sides of the group having the maximum frequency?
- Are the two modes (two groups having maximum frequency) and both the groups are distinctly separated?

Based on the above analysis, it is concluded whether the distribution so obtained is normal or not. If the distribution is successfully concluded as being normal then rejection, analysis is done using σ wherein projected rejection percentage above and below USL and LSL, respectively, is calculated along with the C_p and C_{pk}

As for process centering drift analysis, the guidelines have been derived from the WECO; rules (refer section 2.1.2). The guidelines are:

1. No points outside the control limits on average chart plotted (indicates that the variation in the process centering is consistent with the inherent sources of variation)
2. Seven consecutive points increasing or decreasing (indicates that the process center is gradually getting drifted may be because of the tool wear).
3. Seven consecutive points on one side of the central line (indicates that the process center has changed from one position to another position).
4. Shift from one end to the other end (indicates shift in the process center suddenly).
5. Patterns and cyclical variations.

In order to gauge the capability of the measurement system the gauge R&R value is calculated and the decision on the gauge and its usage is decided based on the guidelines given below:

1. If the repeatability variation of the gauge is high as compared to the reproducibility variation then the gauge is used subject to the options available that is the use of gauge in other area.
2. If the reproducibility variation of the gauge is high, as compared to the repeatability variation then the skill of operator is in question and hence the method of gauge utilization and the operator training are dealt with
3. If the P/T (precision/tolerance band) ratio or total variation of gauge/ total process variation ratio is:

- < 10% then gauge is acceptable and capable
- 10-20% then the gauge is acceptable with certain modifications
- > 20% then the gauge is not capable and should be rejected

Note: here the precision is 5.15 multiplied by the standard deviation of the total gauge variation assuming that the 99% of the data population are measured correctly. The guidelines for gauge R&R are more or less based on the guidelines given in section 2.1.2.2.

3.3.1.1 Experiment details

Taking cue from the above standard process control procedure and for the actual feel of the SPC system at the shop, an experiment has been conducted at one of the workstation, Parishudh Machine Pvt. Ltd (PMPL) make facing head CNC internal grinding machine, which is machining the following dimensions of the third gear of gearbox GBS 18 (refer appendix A):

1. Bore dia:	46.998 to 47.012 mm, target value is 47mm
2. Cone angle:	6° 58' to 7° 2', target value is 7°
3. Cone dia:	81.578 to 81.6mm, target value is 81.6mm

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3. Cone dia: 81.578 to 81.6mm, target value is 81.6mm

4. Ungrounded face run out: Maximum of 100 microns

It is observed that for the bore diameter and the ungrounded face run out, the measurements are taken by the operator in-charge of the machine. For the cone angle and the cone diameter samples are sent to the metrology lab for measurements on request. The inspection for bore diameter and ungrounded face run out is done 100% and for the other two it is 5 pieces per hour. The complete study has been done on this machine since the gauge R&R for all the dimensions on it are under the acceptable limit and this machines most of the critical dimensions of the gear. Few important features of the experiment are as listed below:

- The data has been collected in a total of three shifts just after the initial setting for the 3rd gear taken into production got completed
- The data has been collected on the existing measuring instruments with allowable gauge R&R.
- The data has been collected by total of four different operators.
- The data has been collected without any instructions in order to catch overall variation with assignable and chance causes.
- In between slight adjustments are considered as the part of the process but no setting change is done.
- Analog dial gauge is applied for the run out and pressure gauge with the master of 47.008mm is applied for the bore size.

As far as control charts usage is concerned only X-bar R chart is used and that too with the warning limit of ± 1 sigma. These control charts are used for the cone angle and cone diameter since there is no 100% inspection for these characteristics. The process is to track the measurement of 5 pieces every hour for both the cone angle and diameter If the piece is within the limit of ± 1 sigma then no action is taken but if it is out of this limit

then the action is taken and one piece out of every three pieces is inspected till the process is stable.

As for the bore diameter, the 100% inspection assures the required dimension within limits and in case the operator observes any shift in the successive three readings from the mean on either side then the corrective action is initiated in the form of correction made in the CNC program. For these deviations as such no root cause analysis is done.

The ungrounded face run out is inspected 100% percent using analog dial gauge. Here the variation observed is not much vis a vis the tolerance. The operator is least bothered in adjusting this dimension as such but as mentioned above, is inspecting each and every piece.

3.3.1.2 Result summary of the process capability study conducted

Above mentioned all the four dimensions have been studied for the probability plot and process capability. Around 150 pieces of third gear have been inspected continuously without any sort of resetting. The resulting readings have been then worked on the standard software MINITAB for the values of C_p, C_{pk} (potential process capability indices), P_p, P_{pk} (overall process capability indices) and goodness of fit Anderson Darling coefficient (AD). The results of the same are as tabulated in table 3.1 (refer appendix B).

Table 3.1: Capability study result summary

	Process indices and coefficients				
Dimensions	C_p	C_{pk}	P_p	P_{pk}	AD
Bore diameter	1.06	1.01	0.84	0.8	2 629
Ungrounded face run out	2.22	3.06	2.13	2.94	11.54
Cone angle	0 8	0 69	0.26	0.23	0.613
Cone diameter	1.04	0.98	0.71	0 66	0 792

From the above table the marked readings indicate few abnormalities The C_{pk} of the ungrounded face run out is more than the C_p. This is because of the fact that the tolerance for the run out is on the positive side, which is from 0 to 100 micron, and hence the C_{pk} is basically the C_{pu} value of the upper tolerance.

Coming to the AD coefficient of the probability plot of the ungrounded face run out we observe that it is very high, indicating that the distribution is far off from the Normal as assumed for the capability study. The reason for this is the gauge used for taking the readings is an analog dial gauge with the least count of 10 micron as a result the readings when taken by the operator are rounded off to the nearest value say 30 or 20 micron. As a result, the readings got stacked on few values and hence such an absurd distribution has been obtained. However, since the C_{pu} is around 3 06 there is no need to place a more accurate gauge.

The difference between the C_p and P_p values obtained for the cone angle and the cone diameter is substantial. This clearly indicates that the in between subgroup variations are to an extent substantial vis a vis within subgroup variations or in other words the variation due to the assignable causes is substantial vis a vis the variation due to the

chance causes. That is, the process is, to an extent, capable but has a tendency to wander Cause and effect analysis has been done for any defect generated this has been done along with the operator and the shop in-charge the results of the same is given in the form of fish bone diagram.

3.3.1.3 Cause and effect bore diameter oversize/ undersize

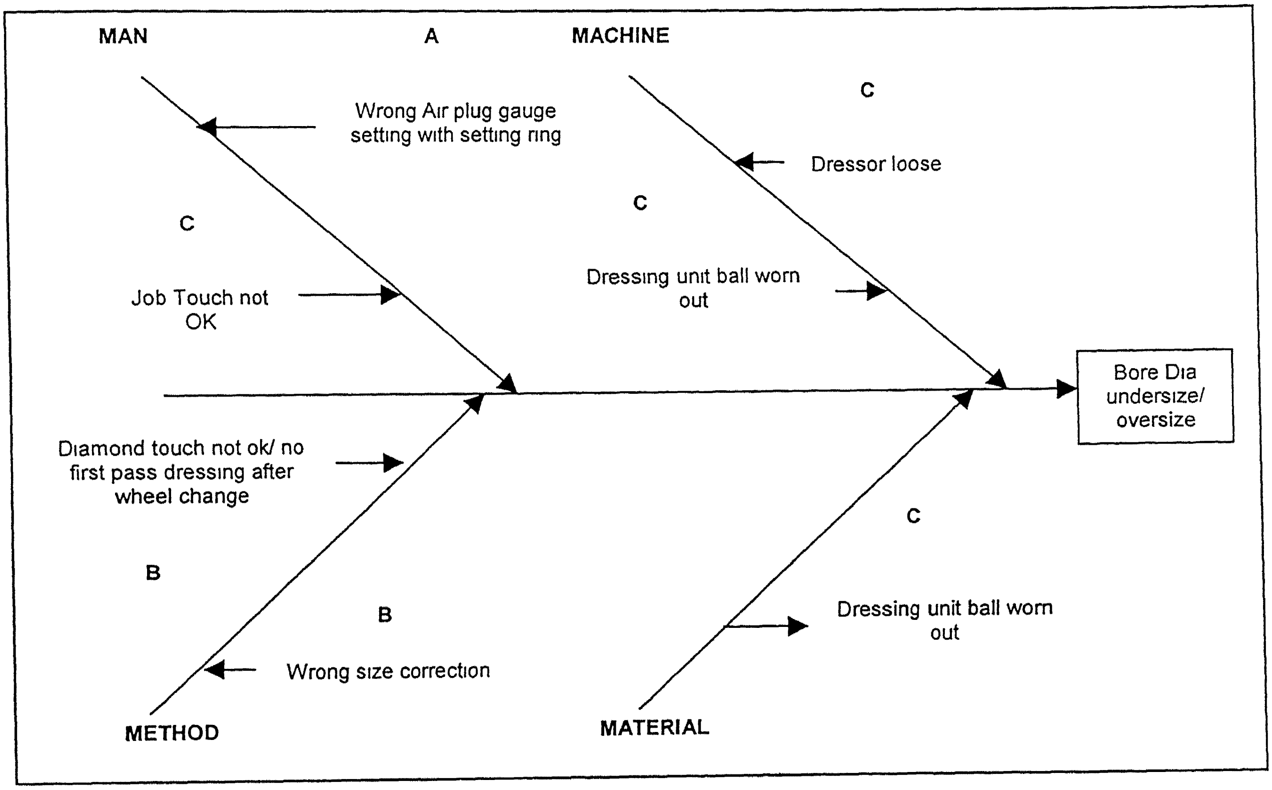

Fig. 3.2: Fishbone bore diameter oversize/undersize

The major causes as such for the variation in the bore diameter are marked as A & B. Here the major cause for variation is the wrong periodic calibration of the air plug gauge with the master setting ring; this is done by the operator in-charge. The other cause is that the dressing should be done after wheel change but is not done by the diamond tip dresser after the grinding wheel is changed. In other cases, the operator wrongly gave

the correction in the CNC program Since there is no preventive mechanism, in some cases, dresser tip of diamond gets worn and hence the dressing is not completed leading to variations In few instances the dresser mounting got loose leading to incomplete dressing of the grinding wheel and hence variations in the bore diameter

3.3.1.4 Cause and effect cone diameter oversize/undersize

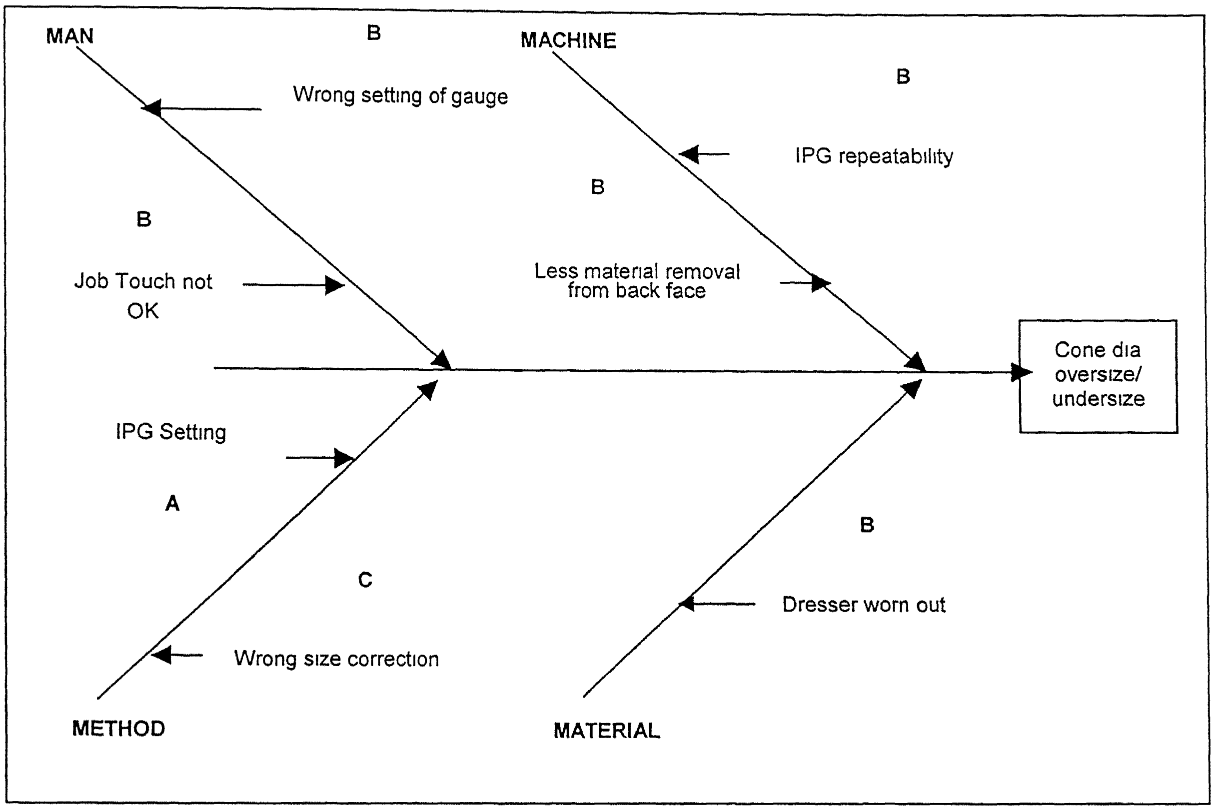

Fig. 3.3: Fishbone cone diameter oversize/undersize.

The variations in the cone diameter are mainly due to the in process gauge (IPG) setting The IPG comprises of two fingers and during the machining process of the diameter, these fingers are in contact with the surface of the cone As the preset limit arrives, the fingers sense it and gauge sends a signal, thus the tool retracts If the preset

limit is wrong in the gauge the variations in diameter occurs The repeatability of IPG is also in question The IPG like any other gauge may show more repeatability variations. The material of gear at its back face is removed to maintain the width of the gear Sometimes variation in this results in variation in the distance from back face to the centerline of cone slope When such a piece is measured, the diameter is measured at a point different then the point on the centerline of cone slope. This results in wrong value of cone diameter although the diameter and angle may have been right

Job touch is done during the setting of the machine The main purpose of job touch is that it fixes the reference point for the machine. It is a regular practice that the operator is impatient and tries to complete the job touch as soon as possible where as job touch should be done slowly with great skill With wrong job touch the gears are manufactured with variations and after detection of wrong job touch, the complete exercise is repeated.

3.3.1.5 Cause and effect cone angle

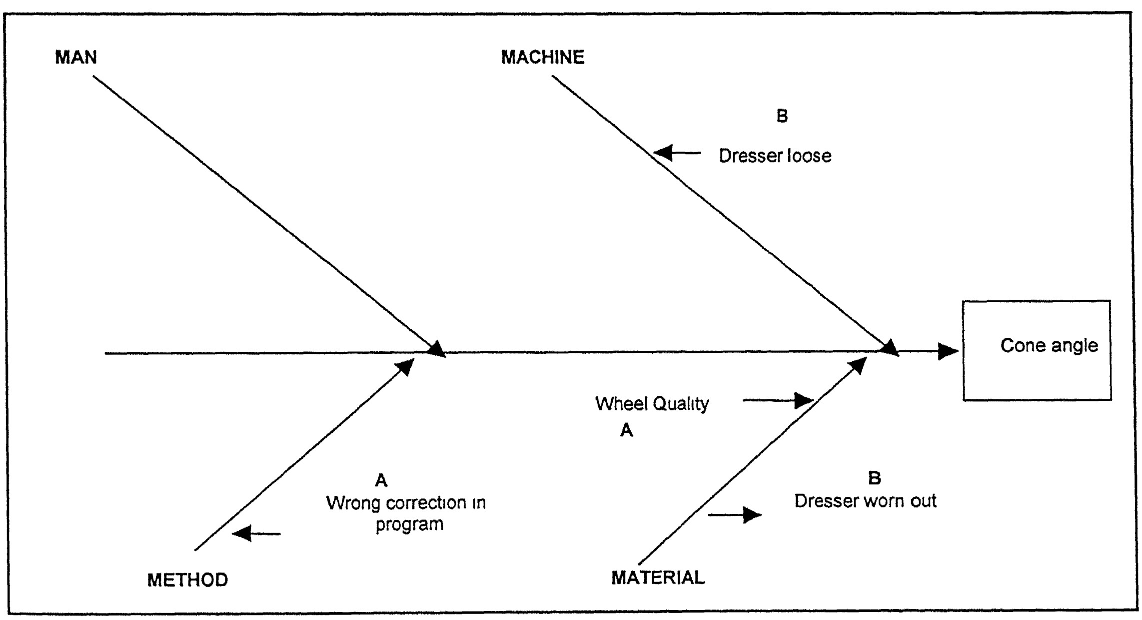

Fig. 3.4: Fishbone cone angle

Most of the causes for cone angle variations have been explained in the previous fishbone diagrams except the wheel quality. Here wheel quality implies that the cone angle variations are directly related to the grinding wheel's surface profile, grinding material on the wheel surface, dimensions of the wheel etc

3.3.1.6 Cause and effect ungrounded face run out > 100 micron

As can be seen in Fig 3 5 there are no A class causes. Thus, the occurrence of this defect is quite low (in fact, it is nil). The chances of variation are more if the operator in charge does not clamp the piece properly before taking the run out using the dial gauge The manufactured piece may be correct but the wrong clamping leads to wrong run out reading

There is low chance that the back plate of the cassette on which the gear is mounted has the high points or slug In addition, the possibility of the cassette plate having the run out. However, if such is the case then the measured run out will vary to great extent. Same is the case if the gear is soiled and is clamped.

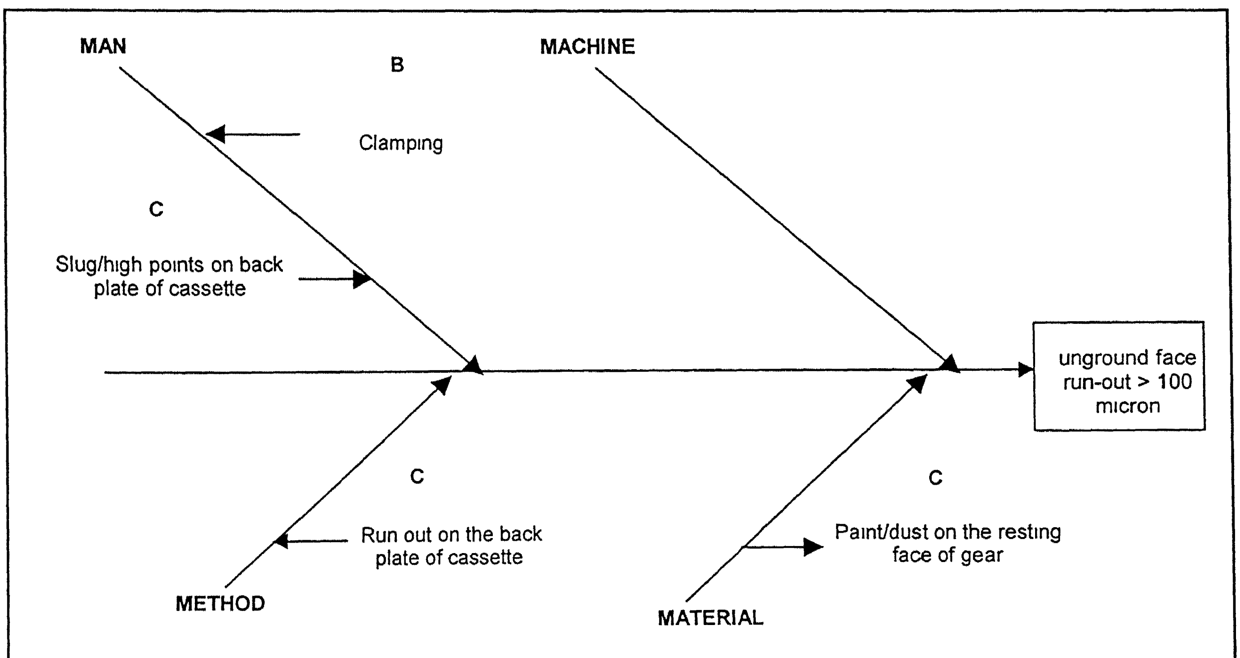

Fig. 3.5: Fishbone ungrounded face run out > 100 micron

3.3.2 *Gap* analysis

As mentioned in the as is analysis the single tool used for the control of the process is X-Bar & R chart. However, these charts are capable for detecting the moderate to the large process shifts. The use of WECO rules to a certain extent make it capable for the smaller shifts but a better option is to either go for the X-Bar and S chart with sample size more than 10 or go for the EWMA chart (refer section 2.1.1 & 2.1.2).

As can be concluded for the characteristics like the cone angle and the cone diameter, wherein the shift in the process mean is frequent, employing the EWMA chart will signal the shift much before the damage and hence it is advisable to use such charts for such characteristics.

For the sampling frequency, there existed no fixed and derived sampling plan. The criteria for deciding the sampling frequency is not looked into and in-some cases it is mostly left to the operator to decide (refer section 2.3). Before drawing out the sampling plan, the process stability, frequency of process event, sampling cost etc. should be considered [Montgomery, 1997].

The normality assumption of the obtained distribution (histogram) is based on certain guidelines and no statistical tool is applied as such. The probability plot from the MINITAB software can answer the nature of distribution more accurately. Hence, as a periodic review, the nature of distribution could be checked using the software.

It is observed that in normal practice the focus of control is on the individual machines and that too on controlling the characteristics as per the specified tolerances. In fact no effort is been made in knowing the level of product quality and the operating quality level of the machining line There is no mechanism as such to measure the product C_{pk} Index, capability of the machining line and the composite C_{pk} index. The main usage, as such, for the product C_{pk} is that it gives an idea of the net effect of the capabilities of individual machines, for different characteristics, on the product Capability of the line, in effect, is

the product of all the product C_{pk}'s and hence it gives an idea how well a particular machining line or assembly line is performing. Finally, the composite C_{pk} (CC_{pk}) helps in fixing the individual machining center capability targets. The usefulness of these indices is that they help in gauging not only the capability at micro level, say the characteristics, but also on the macro level that is the machining line as a whole [Bothe, 1999].

Another aspect, which needs attention, is of dynamic C_{pk}. It is assumed that in between two samples, there is no shift of the process average but in actual practice, there could be slight temporary shift so that the job pieces are produced with a shifted average. This may lead to more number of defective pieces. These shifts become all the more important when the characteristic is critical. The dynamic C_{pk} incorporates this dynamic nature of the process average assuming the variance to be constant. In most of the actual SPC practices in the industry the adjustments are not made for the calculations of C_{pk} since the people are either, not aware of the dynamic C_{pk} concept or the cost of quality may be going up by implementing it. The proposal is to include the above concept with discrimination on those quality characteristics, which have substantial impact on the product quality and the rejection cost. This will include criticality analyses followed by choosing the desired subgroup size and making adjustments accordingly in calculating the C_{pk} [Bothe, 2002].

3.4 Recommendations and comments

1. Sample size and number of subgroups taken are common and the controlling criteria are common to all the characteristics; where as the shop requirement is different as few characteristics are critical and few are not so. Hence, the same policy for all should not be applied and there should be discrimination at the characteristic level.
2. No fixed review plan is available for the review of the control limits. In fact, the control limits are set after the capability study but as such, no fixed plan exists for their

periodic corrections. For characteristics with frequent process mean shifts and changing spread, the control limits should be reviewed every quarter and for the rest this could be made half yearly.

3 The gauge calibration review plan exists but there is no review plan for the gauge R&R study. It is also observed that the operators are shuffled between the machining centers more frequently but no measurement system analysis (MSA) is done. It is advisable that whenever such changes do occur, the gauge R&R study should be conducted since a new operator with different skill set is the part of the system.

4 Some tolerances are so tight that measuring them is not possible since gauges are not capable and new gauges require heavy investment. However, it is also observed that in most of these the tolerance band could be relaxed. The manufacturing is taking place based on temporary deviations and hence the designer, for some tolerance relaxation, could review these characteristics.

5 There is no attention paid to the interdependencies of the characteristics. As a normal practice, it is assumed that the characteristics are independent of each other, but the complexity of the process clearly indicated the possibilities of the interdependencies. As such, this aspect could become the topic of further research

6. There is no data available on machine life and machine reliability. Apart from this during the cause and effect analysis, many causes came out to be related to the machine. As a result, the user is unable to take action on these causes. A suggestion is to involve representative of the machine manufacturer who can suggest some changes in the machine that can help in increasing the capability of the machine.

7. It is observed that the assignable causes are identified and actions are taken during the construction phase of the control chart and subsequently after that process is rarely reviewed, where as the assignable causes should be identified continuously and eliminated.

8. The technical competency of the shop floor manpower for the statistical control techniques is observed to be low. A good amount of training is required for them to utilize properly these techniques for their day-to-day work.

9 The improvement efforts in the existing processes are seen to be very rare. Mostly the first level cause and effect analysis is done. With the first level of cause and effect diagram, the actions are taken to make the temporary correction. This is the reason that in few characteristics the gear is manufactured correct but the process center variation is frequent and wide. The process improvement flow chart in section 2.5 (refer Fig 2.2) lays clear-cut guidelines for the process improvement. It is suggested that similar kind of model could be developed for the gear shop with support from the other agencies like the top management and the designers. Also special emphasis is to be given for the process of detecting assignable cause and their elimination. The detection of assignable cause is only to the primary level where as in order to remove these, root cause analysis methodology becomes must. An attempt has been made during the experimentation to complete the first level of the root cause analysis, which is manifested in fishbone; diagrams (refer section 3.3.1).

Chapter 4

PROCESS STUDY AND EXPERIMENTATION AT ASSEMBLY SHOP

4.1 Introduction

The study of assembly processes and the experimentation has been done on the assembly line of the Sumo multi utility vehicle. Sumo is one of the leading MUV in domestic market and is available as Sumo SE, which is the base model The other variants of Sumo manufactured are Sumo Ezi, Sumo DX, Sumo Ambulance, Sumo Plus and Spacio. This line has been chosen since it is manufacturing only one model Sumo and its variants. Where as, the medium commercial vehicle (MCV) line is manufacturing as many as 18 models. Hence studying the processes for each and every model is not feasible in the available time.

Initially, a thorough investigation of the assembly process has been done and the layout of the complete line drawn. Then the as is analysis has been completed and all the inspection points on the line identified. The in-use SQC tools have been looked for and their usage on the line studied. The experiment has been conducted to look for the possibility of applying attribute control charts on the assembly line. The data has been collected from the TE/LP assembly line check sheets, plotted and tested for confirming the distribution. Based on the results the control charts for assembly line have been suggested.

4.2 Process study

The production process at assembly shop relates mainly to the production of regular vehicle models. The flow chart and other details of the process are given below. The

complete Sumo assembly line can be divided into three major areas with the Sub areas as Listed below

Cab assembly

Rectification and touch up: The bare shells are not manufactured in house, instead are bought from the TATA Engineering Pune plant in a completely painted condition since there is no fabrication and paint shop at TATA Engineering Lucknow. During the transportation, there is a possibility of sheet or paint film damage. The main job of the rectification and touch up line is to rectify the received shells before transferring them to the trim assembly

The line consists of five stations in all, first is for the incoming inspection, second for the damage rectification, third is the paint booth, fourth is a baking oven for drying the touch up and the fifth and final is the top-of-line inspection.

Trim assembly: Once the body shell is through the rectification and touch up line, it is fed to the trim line, which comprises of twelve stations. First station is for the roof lining hanging and mud liner fitting. Glue spray on the roof lining is done on the second station. Operators cut and stick the roof lining at the third station. Door locks and front and rear windscreen glasses are fitted at the fourth station. Engine wiring harness is fitted at the fifth station. After this the window -winding regulator on all four doors is fitted at station number six. The window glasses are fitted to the window-winding regulator at seventh station. The seats are fitted at the eighth station. Door-pads are fitted at the ninth station. A complete dashboard subassembly is fitted at the tenth station and testing of the instrument panel and combi switch is done at the eleventh station. Final inspection takes place at the twelfth station and then the cab is towed to the cab drop station indicated by curved arrow in fig 4.1.

Chassis assembly

Frame assembly: Initially rectified frames are fitted with Main wiring harness and the steering gear box subassembly, after this the stub axle subassembly and the propeller shaft is fitted. Finally, the tyres are fitted to the frame and the frame assembly is pushed on to the first station of chassis fitments and cab drop.

Chassis fitments and cab drop: on the first station, the fuel tank is fitted on to the frame chassis. Next, the bumper brackets are fitted and chassis number is punched At the third station, the silencer and the fuel filter are fitted. Engine is fitted at the fourth and fifth station The sixth station is for dropping the finished cab over the chassis. The dropped cab is tightened at the seventh station. At eighth station radiator, air filter and steering wheel are fitted. After doing brake bleeding and the beam alignment at station ninth and tenth respectively the complete vehicle is sent for the wheel alignment.

Wheel alignment: This is a single station area where the important specifications of the steering geometry are maintained in the vehicle.

Rectification

Road test and mechanical: After the wheel alignment, the complete vehicle is driven and tested for the functional defects if any. The mechanical defects like mounting loose, brake fluid leaking etc are also checked and rectified.

Final inspection and rectification The completely rectified vehicle is then finally inspected and is sent to the dispatch section after some minor rectification.

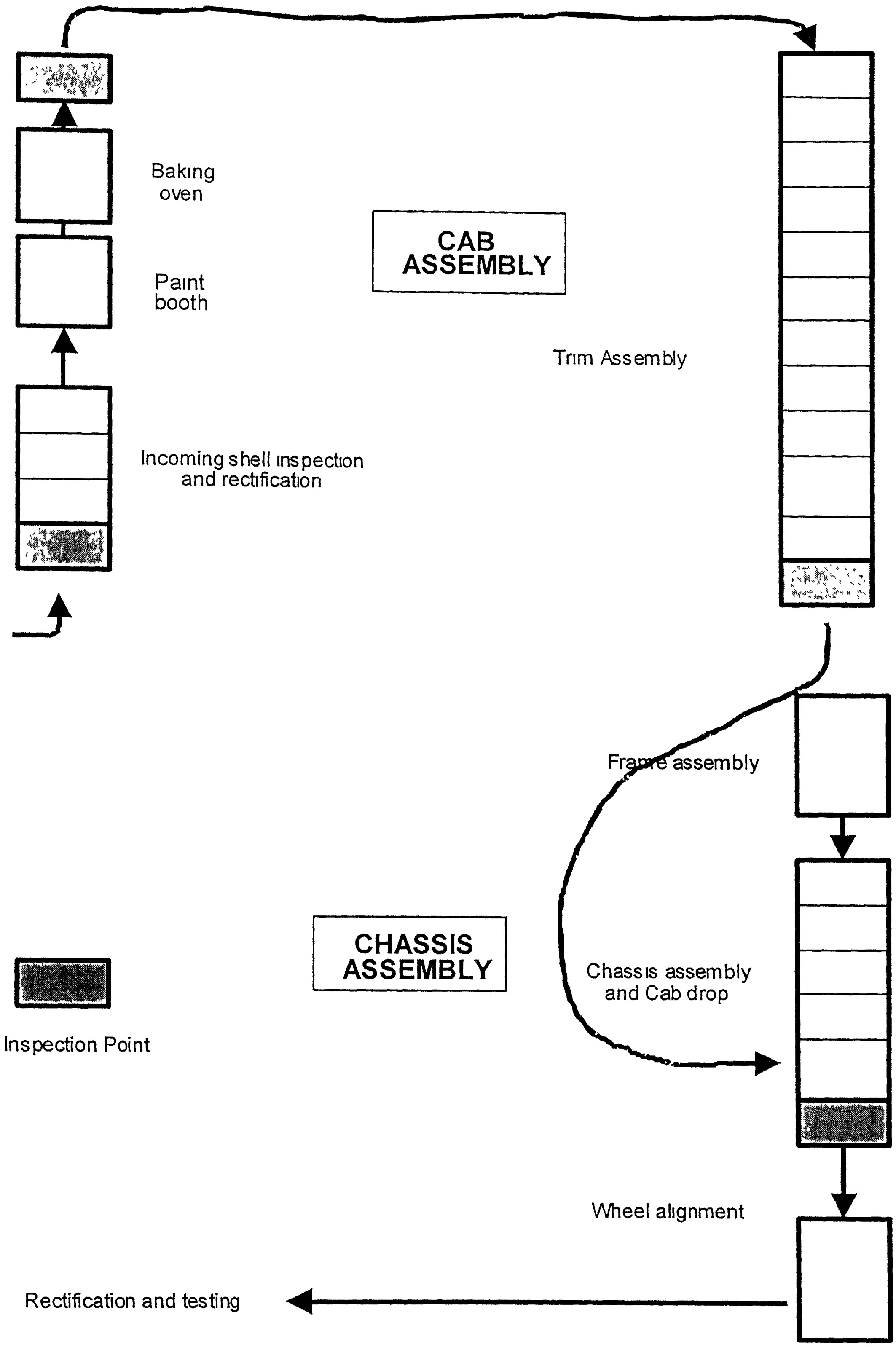

Fig. 4.1: Process layout Sumo assembly line

4.3 Experimentation and analysis

The experiment has been conducted and the as is analysis, along with the gap analysis, has been done. The recommendations based on these are also given.

4.3.1 *As is* analysis at assembly line

The in-process inspection at the assembly line is done at the following places:

- First station of paint line.
- Last station of the paint line
- Last station of the Trim line
- Last station of the chassis line.
- At road testing.
- Before dispatch

The point to be noted is that the inspection is done for 100% vehicles at all the above-mentioned points. As for the process control, the techniques and the tools employed are.

- Check sheet
- Histogram
- Pareto chart
- Cause and effect Diagram

Check sheet: There are three check sheets on the complete line. First, one is at the paint line, second at the trim assembly and the third one is with two parts, one for the chassis assembly and another for road testing and mechanical. These check sheets are having coded defect description and the instructions along with the technical specifications. On the line, this sheet is known as the inspection card of respective area.

Histogram: The data from the check sheets is collected at the end of the day and is fed into the database that is linked to the histograms of different types like histogram of trim assembly defects, chassis assembly defects, road test defects etc. The updated

histograms are refreshed and displayed every week to indicate the rising frequency of defects. These are also used as the tool for controlling a specific defect by making things clearer to the operator. This is an important tool for the process control and is a part of visual display system.

Pareto chart: The pareto chart is used for monthly defect analysis and for reporting. The data from the histograms is compiled and then the most occurring defect list is prepared. This is represented in the form of pareto chart for the line operators to look at and improve. The shop manager and the top management also use the pareto chart obtained for attacking the areas of concern

Cause and effect Diagram: The cause and effect diagram is used by the quality circles as well as to thrash out day-to-day problems on the assembly line. The use of the cause and effect diagram is not so extensive.

The use of the control charts is not at all to be seen on the assembly line. An experiment has been conducted in order to find out whether there is any possibility of using control charts.

4.3.1.1 Experiment details

The experiment has been conducted at the final rectification area where almost all the defects whether of trim assembly, paint line or chassis assembly are captured. The data has been collected from the check sheet and divided into four major heads.

- Major mechanical defects
- Minor mechanical defects
- Major trim defects
- Minor trim defects

The main aim of the experiment is to draw the frequency distribution of each and every head and look for the possibilities for implementing control charts so that the existing system of inspection at multiple points and repeat inspections could be avoided. The defects per vehicle have been calculated and compared with the probability mass function of Poisson distribution with the parameter λ (mean) calculated from the data collected during the experiment. The frequency distribution histograms are as follows

4.3.1.2 Results

Frequency distribution (total defects):

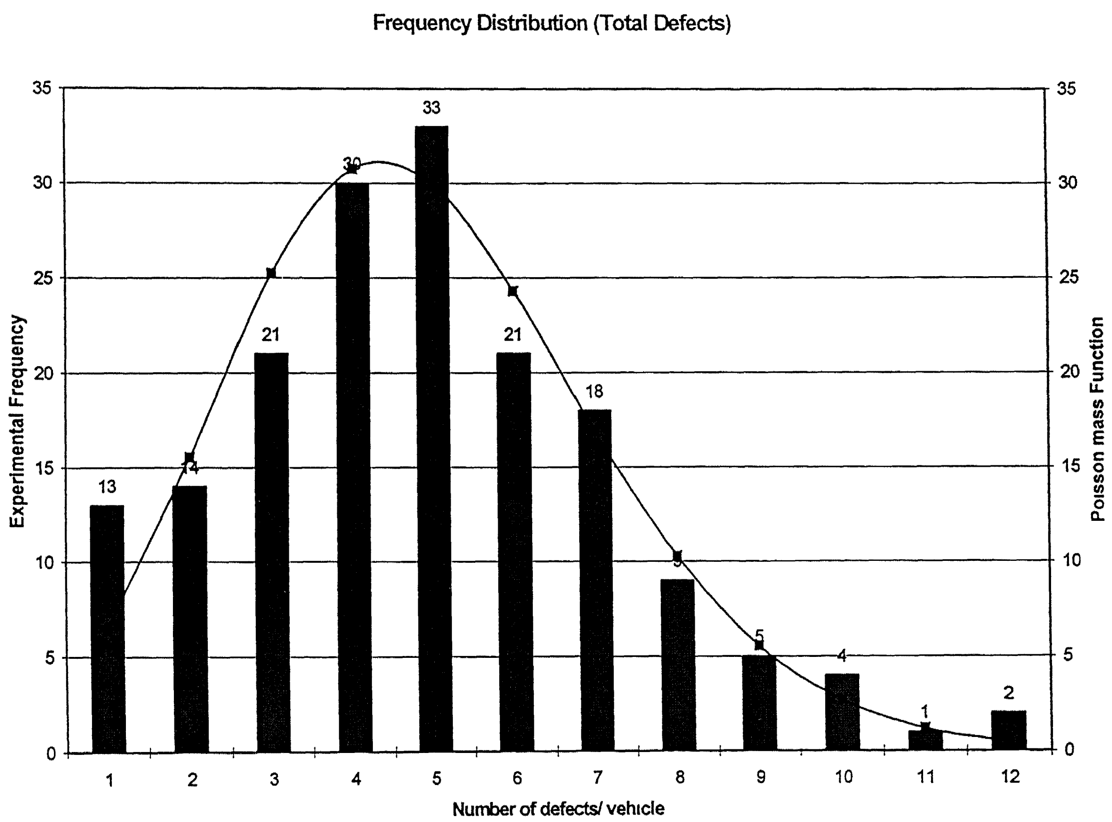

Fig. 4.2: Frequency distribution (total defects)

The above distribution approximates the Poisson distribution with λ=4 87 the value of the standard deviation σ is 2 2. Thus the control chart taking total defects all alone will have the UCL = 11 47 and LCL = 0, with mean = 4 87. The UCL and mean should be rounded to the nearest value.

Frequency distribution (major mechanical defects):

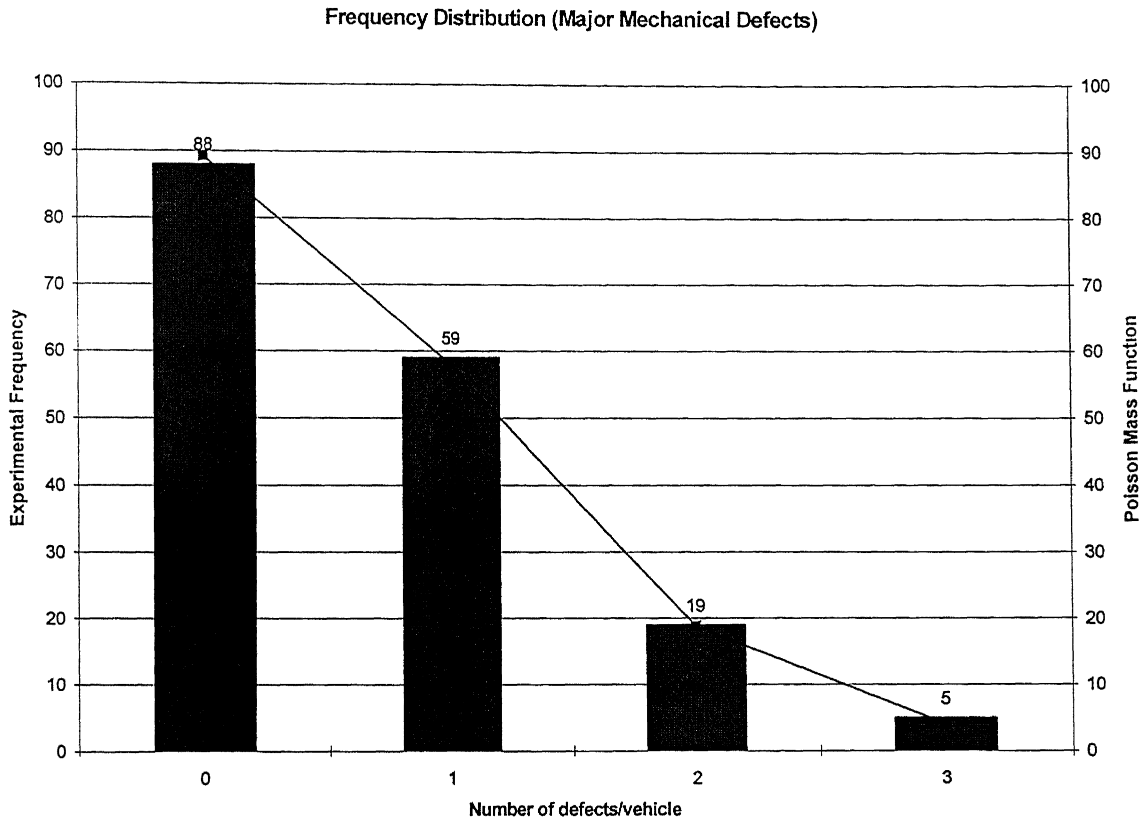

Fig. 4.3: Frequency distribution (major mechanical defects)

The above distribution approximates the Poisson distribution with λ= 0 .65 the value of the standard deviation σ is 0.81. Thus the control chart taking major mechanical defects all alone will have the UCL = 3.08 and LCL = 0, with mean = 0.65. The UCL and mean should be rounded to the nearest value.

Frequency distribution (minor mechanical defects):

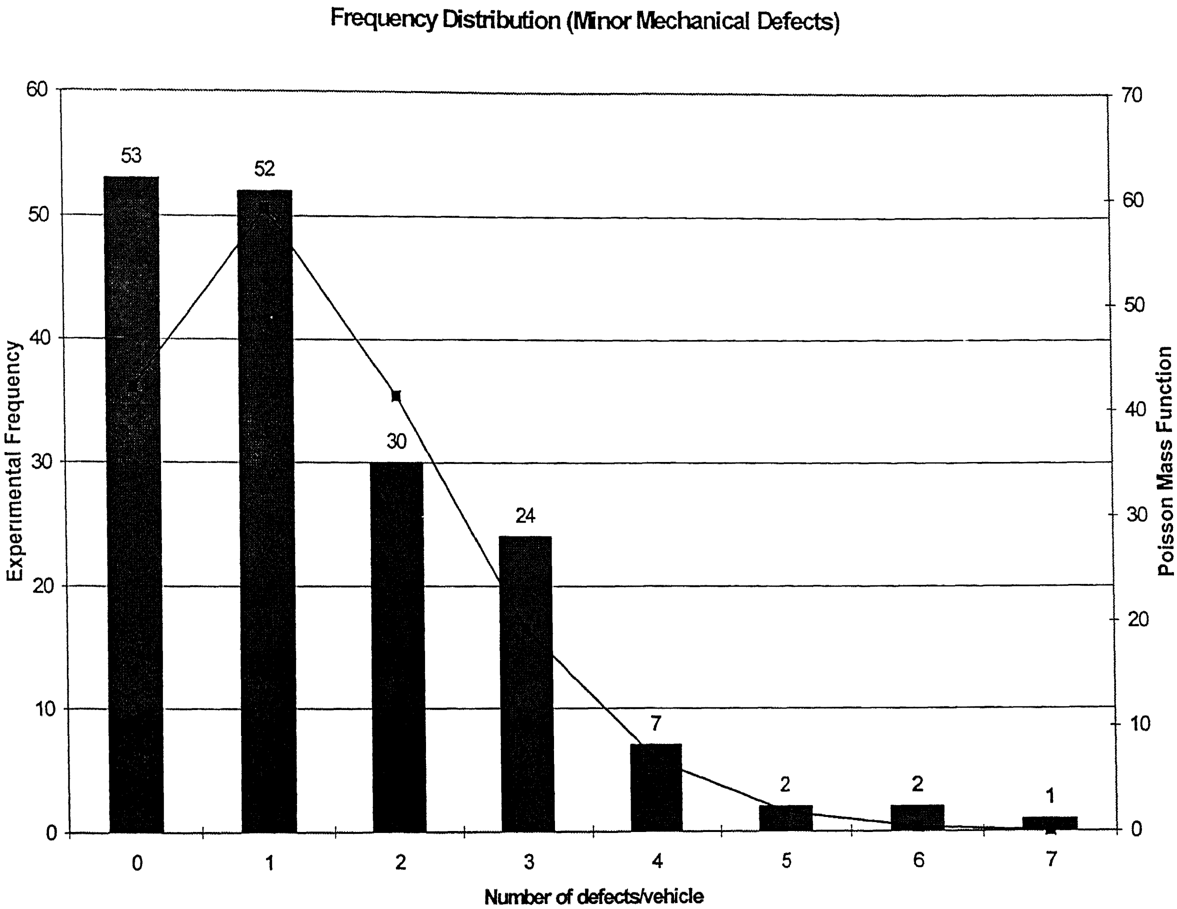

Fig. 4.4: Frequency distribution (minor mechanical defects)

The above distribution approximates the Poisson distribution with λ= 1 4 the value of the standard deviation σ is 1.19. Thus the control chart taking minor mechanical defects all alone will have the UCL = 4.97 and LCL = 0, with mean = 1.4 The UCL and mean should be rounded to the nearest value.

Frequency distribution (major trim defects):

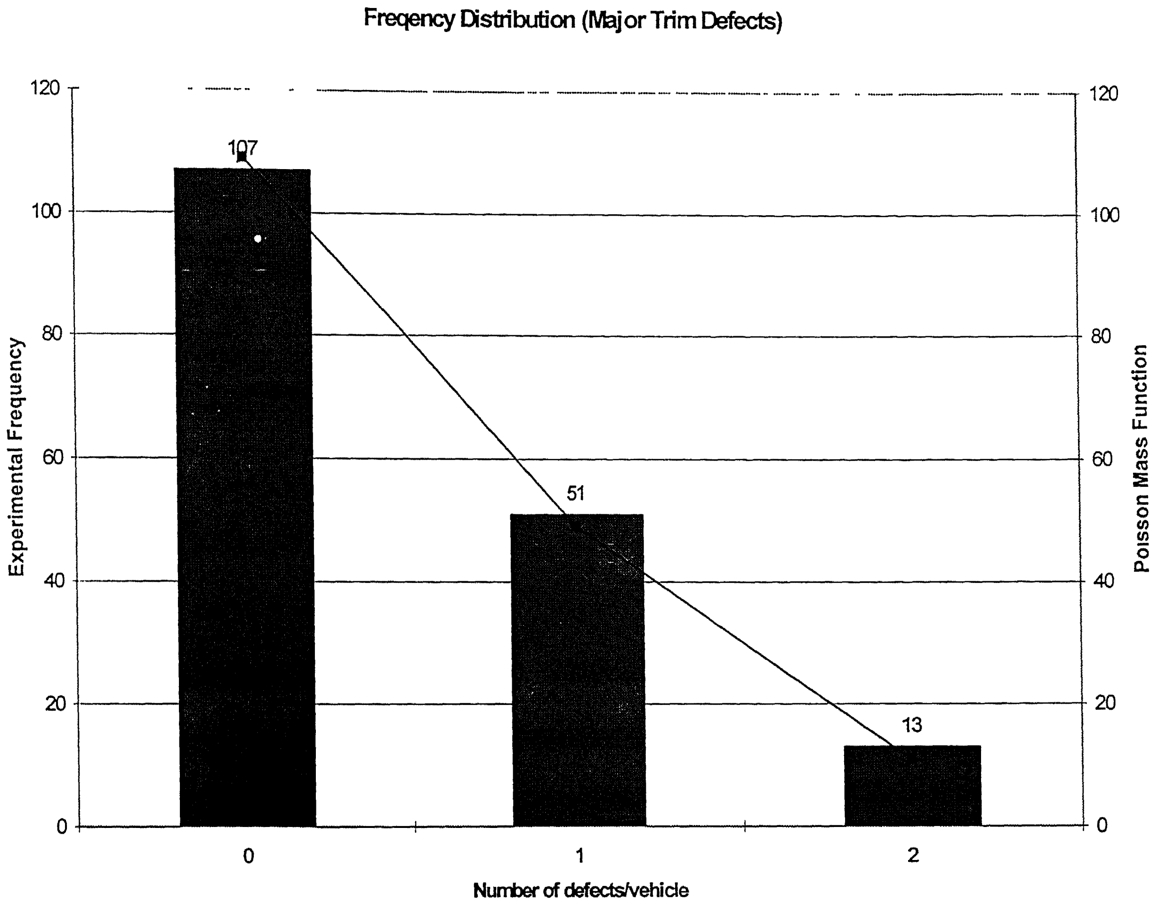

Fig. 4.5: Frequency distribution (major trim defects)

The above distribution approximates the Poisson distribution with λ= 0 45 the value of the standard deviation σ is 0.67. Thus the control chart taking major trim defects all alone will have the UCL = 2.46 and LCL = 0, with mean = 0.45. The UCL and mean should be rounded to the nearest value.

Frequency distribution (minor trim defects):

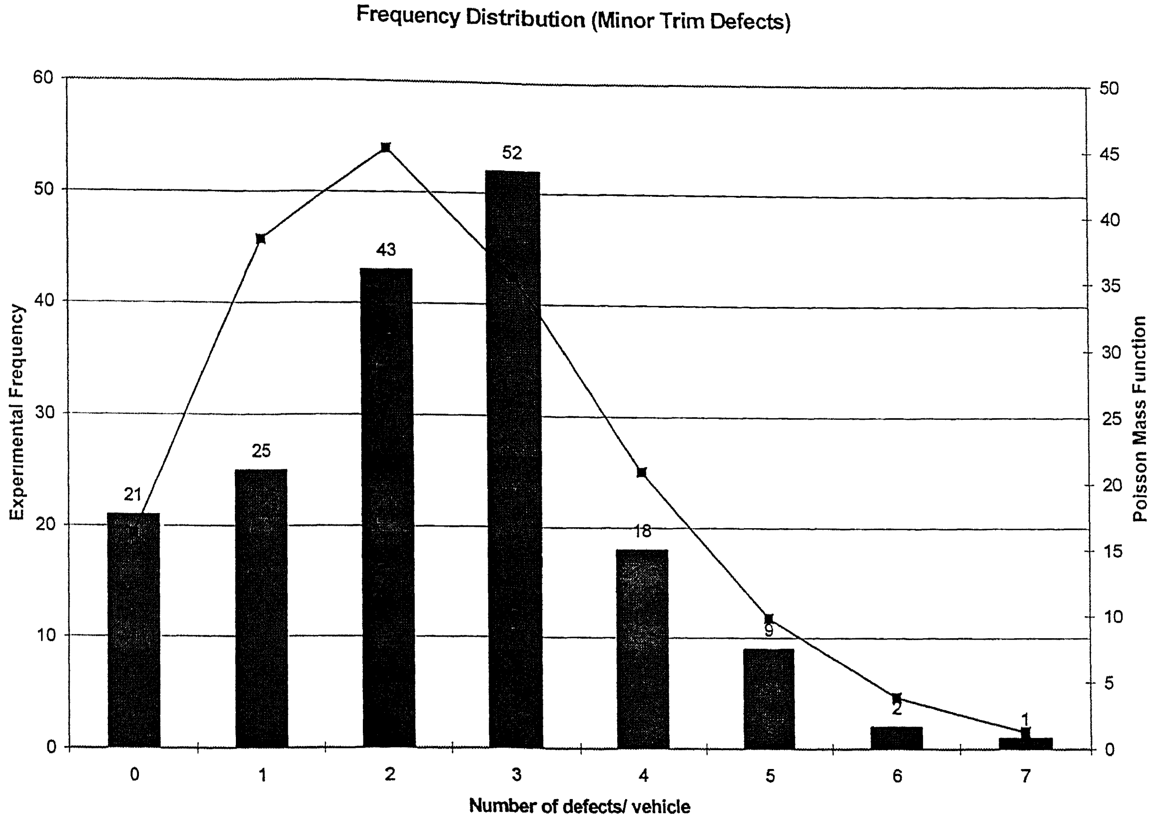

Fig. 4.6: Frequency distribution (minor trim defects)

The above distribution approximates the Poisson distribution with λ= 2.36 the value of the standard deviation σ is 1.54. Thus the control chart taking minor trim defects all alone will have the UCL = 6.98 and LCL = 0, with mean = 2 36. The UCL and mean should be rounded to the nearest value.

As observed from the fig 4.2, 4 4 & 4.6, and the calculations, the variability of total and minor defects is quite high. The user group of the control chart can fix the specification limits according to its requirements and monitor the variability of the process. It can try to bring the control limits within the specification limit and will have a good idea of the process behavior.

In the above analysis, initially, data from a hundred vehicles has been taken but the distributions did not come out clear. This has been increased to 150 vehicles, and ultimately to 171 vehicles, so that the clear-cut distributions could be obtained for each head. The major problem is with the major defects since their occurrence is quite low in a vehicle, in order to obtain a measurable distribution the size of the data set has increased. Since the data is discrete, hence the chi square goodness of fit test has been employed. The results of the test are tabulated below and have been calculated using software developed by Harsham [Harsham, 1996]

Table 4.1: Chi-square goodness of fit test results

Defect Class	Chi Square Value	P-Value	Conclusion
Total defects	11.922	0 369	No evidence to reject the hypothesis
Major mechanical	0.0284	0.999	No evidence to reject the hypothesis
Minor mechanical	8 768	0.27	No evidence to reject the hypothesis
Major trim	0.14	0.932	No evidence to reject the hypothesis
Minor trim	15.26	0.033	Moderate could be rejected

The null hypothesis is

***H0**: The observed frequency table fits the claimed distribution.*

The decision regarding the acceptance of the hypothesis is generated by the software and as mentioned in the table only the Minor Trim defects distribution is moderately acceptable. Here a point is to be noted that the claimed distribution is taken to be Poisson and the expected frequencies have been calculated from the Poisson mass function for the values of λ calculated form the observed distribution.

4.3.2 *Gap* analysis

The in-process inspection at the assembly line is for all the vehicles and as such, no control charts are being used Some statistical techniques as mentioned in the section 4.2 1 are applied in order to analyze the defect trend and pattern and single out the most occurring defects

There is no classification of defects as such and each and every defect is weighted equally. In addition, the inspection of same defect is taking place at multiple stations on the assembly line, for example, the trim defects are checked at the trim line, chassis line and at the final rectification. Thus, there is over inspection, which results in delays and wastage of manpower

For gauging the vehicle quality, an index is used which is known as product quality rating index (PQR). This index is used by the central quality department in order to gauge the quality level of the vehicle produced per day. The defects have been categorized into critical, major and minor with the weights of 10, 5 and 2 respectively. A vehicle is taken in a day's production and based on the number of defects in each category the weighted average is calculated. More the value of the average, poorer is the quality rating. Although this index throws some light on the level of vehicle quality but since it is taken from a single vehicle, it cannot represent the quality level at line.

4.4 Recommendations and comments

With complex products such as automobiles, we usually find that many different types of nonconformity or defects can occur. Not all of these defects are equally important. A unit of product having one very serious defect would probably be classified as nonconforming to requirements, but a unit having several minor defects might not necessarily be nonconforming. In such situations, we can apply demerit System

[Montgomery, 1997] to classify nonconformity or defects according to severity and to weigh the various types of defects in reasonable manner.

Basically, the product (it could be a complete vehicle or a subsystem) can be approached in the following four ways.

1) Treating vehicle as a sample with n=1 and listing all the serious (could be major, minor or critical) defects as opportunities for nonconformance. The control chart will be either a c-chart or a u-chart

2) Treating a subsystem of a vehicle (e g. brake subsystem, transmission subsystem, engine subsystem, suspension subsystem, electrical subsystem etc.) as a sample with n=1 and listing all the serious defects of subsystem as opportunities for nonconformance. The control chart will be either a c-chart or a u-chart for each subsystem separately

3) Applying demerit system to a vehicle or group of vehicles and classifying opportunities for nonconformance in class A, B, C and D.

4) Applying demerit system to a subsystem of a or group of vehicles and classifying opportunities for nonconformance in class A, B, C & D for each subsystem separately.

Here the A, B, C & D, are the classes of defect

i. Class A defects: very serious

ii Class B defects: serious

iii. Class C defects: moderately serious

iv Class D defects: minor

In the experiment, only two classes have been made to have a feel of defects distribution The line in-charge can classify the defects according to his requirements. However, for our purpose it will be major and minor defects. The analysis under first approach {bulleted as 1)} has been completed along with the frequency distributions. If a single control chart is desired then under third approach {bulleted as 3)} demerit System concept can be applied [Montgomery, 1997]. The weight of a major defect is 5 and for the minor defect, it is 2 in line with plant practice. The results after calculations are as given below (refer appendix C)

- u_{major} = 1 11
- u_{minor} = 3.77
- u (center line) = 13 06
- σ = 0.5
- UCL = 14.56
- LCL =11.56

Thus, the weighted average of sample should be in between 14.56 to 11 56. This type of control chart can be placed at the trim assembly and chassis assembly. The sample of sample size 5 vehicles can be taken in a day's production, which is currently near to 30 vehicles and the weighted average should be plotted This will result in sample-based inspection instead of the 100% inspection, which is being done presently

In the above analysis, it has been assumed that the frequency distribution of the individual defect category say major mechanical defects or minor trim defects is Poisson distribution In the experiment, the data has been collected, histograms drawn and comparison has been made with the probability mass function of the Poisson distribution having the parameter λ as estimated from the collected data. In most of the cases, the distribution has matched except that of minor trim defects (Fig 4 6).

In cases where the distribution doesn't match with the standard frequency distribution, the control chart based on the obtained empirical distribution are used but the criteria for the upper control limit and the lower control limit mostly depends upon the shop practices and the requirements of the product manufactured.

Chapter 5

CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

5.1 Conclusions

It is evident that the statistical process control techniques are being utilized in Tata Engineering/Lucknow plant, but these techniques are quite old and need to be improved upon The usage of control charts in the gear shop is very much limited in the sense that only the X- Bar & R chart is used. One of the main reasons for its wider acceptability is that it is very easy to understand and apply. The selection procedure for selecting the most suitable control chart for various processes as such is missing and X-Bar & R chart is the panacea for process control. The flowchart (refer fig 2.1) should be referred to for the rational selection of the control charts for various processes The out of control and non-random situations are gauged on the WECO guidelines. The use of EWMA chart can provide much accurate out of control situations and should be used where ever felt to be suitable instead of WECO guidelines, since chances of false alarm are high (refer section 2.1.2) with these rules.

The sampling criteria and the control limits review plan needs to be strengthened. It is observed that the sampling is more on the hunch of the operator The sample size in some cases is not fixed. The subgroup selection and the frequency of sampling may be guided by the approach mentioned in section 2.3. Also, the control limits (process capability has changed over a period of time) once fixed are not reviewed. The within subgroup variation (because of chance causes) may increase or decrease, in all possibilities the spread of the distribution varies and the control limits should be reviewed quarterly or half-yearly by recalculating the potential capability and overall capability.

The problem solving approach needs improvement. The root cause analysis and failure mode and effects analysis (FMEA) on the assignable causes is missing Rare attempts are made to remove the assignable causes and make the process more stable. The flowchart in section 2 4 should become the guidelines and actions based on this flowchart should be taken in designing and using the control charts. The technique of root cause analysis should be exploited to thrash out the assignable causes making process more stable

Proper training should be imparted to the shop floor operators since the competency in using the SPC tools and techniques has been missing. The extensive use of these tools and techniques needs to be encouraged.

On the assembly line, the frequency distribution of the occurrence of the defects in a vehicle came out to be Poisson and it is shown that the u or c chart could be applied taking a particular category say major trim assembly defects to draw a control chart. demerit system could be applied (it is shown that the distribution of all defect classes taken individually, is Poisson) for a single control chart taking all the defect classes together.

The attribute control charts can be employed at the end of the trim assembly and the chassis fitments and cab drop line since all the completed vehicles as such are inspected during the road test and final rectification. Hence, 100% inspection on the mentioned two points at the top of the line does not make sense. Instead, control charts should be employed and sampling based inspection should be done. The user organization should decide to either use an individual c or u chart for every defect class or a single control chart taking all the defect classes together as explained for the demerit system (refer appendix C).

5.2 Directions for future research

- It is observed that the root cause analysis on the defects of the gears is not done. One of the major reasons for this is the complex CNC machine. Shop operator and also shop in-charge do have but a very little knowledge of it That is why no design of experiment (DOE) exercise has taken place till date. This could be taken as a topic for further research in order to find out much better new processes or improve the existing ones.
- In this thesis, the stress is on the current control charts and these are mostly the X-bar & R charts whereas the type of chart depends upon the nature of shifts in the average At a few places, EWMA chart is felt to be useful and at others, the Shewhart chart, while in some cases a combination of both. The usage of hybrid Shewhart-EWMA chart and its applicability, especially in processes with large and small shifts, can become another topic of research.
- The analysis in the gear shop has been conducted mostly on those characteristics, which are independent of each other and also of the assembly However, there are many characteristics, which depend upon each other and affect the quality of the final product. Research on such characteristics will help in improving the product quality further.
- For the applicability of control charts on an assembly line a single model with few variants assembly line is taken for experimentation. This line has a single assembly process since the variants do not vary much from the base model. However, if the line rolls out many models and each model is having different assembly process, then in that case the applicability of control chart to the product mix becomes difficult. This could be taken as a challenge for further research.

- In the discussion of the demerit system and application of the control charts to the assembly line, vehicle has been taken as the product. However, since the complete vehicle is complex and as a requirement control chart is to be designed for the sub-system taking it to be a product, the analysis becomes difficult. Control charts for the sub-systems of a vehicle could be another topic of research
- In the analysis of the frequency distribution for major and minor defects, the distributions are more or less Poisson. However, there may be cases when the distributions obtained may not follow any standard distribution. Designing control charts for empirical distribution could be another topic for research.

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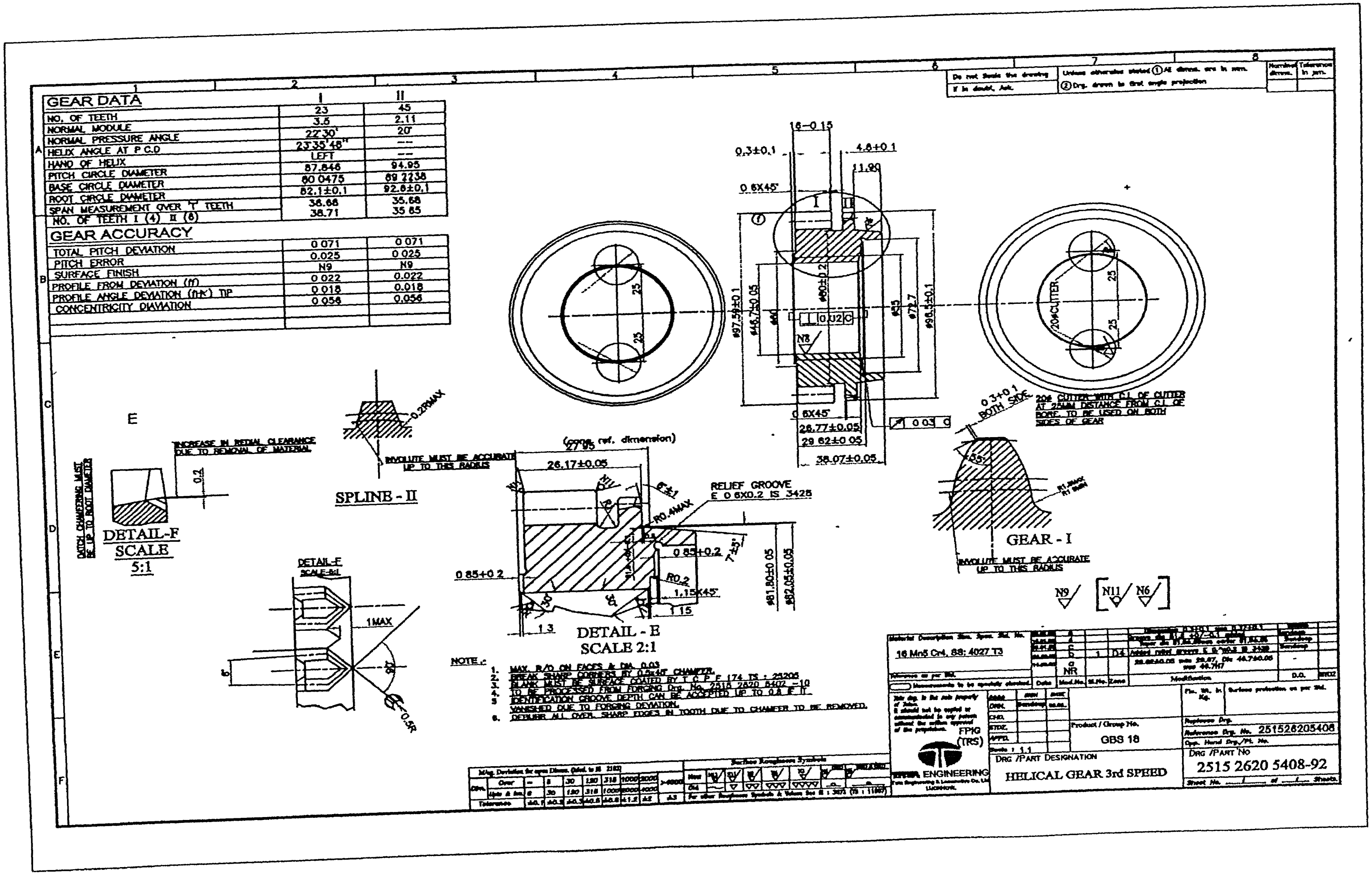
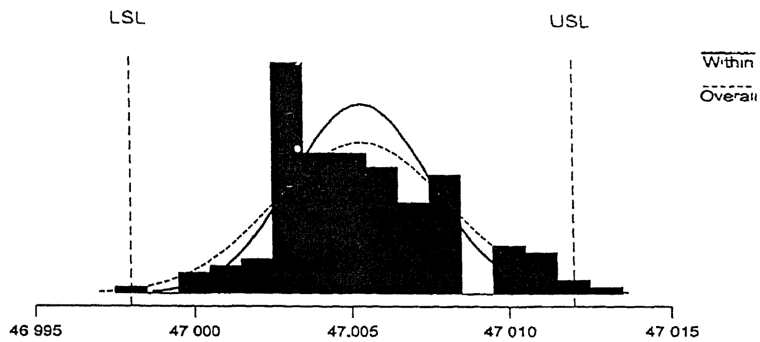


Fig. A-1: Drawing of 3rd Speed gear of GBS 18

Process Capability Analysis for Bore Dia

Process Data	
USL	47 0120
Target	*
LSL	46 9980
Mean	47 0053
Sample N	150
StDev (Within)	0 0022099
StDev (Overall)	0 0027768

Potential (Within) Capability	
Cp	1 06
CPU	1 01
CPL	1 11
Cpk	1 01
Cpm	*

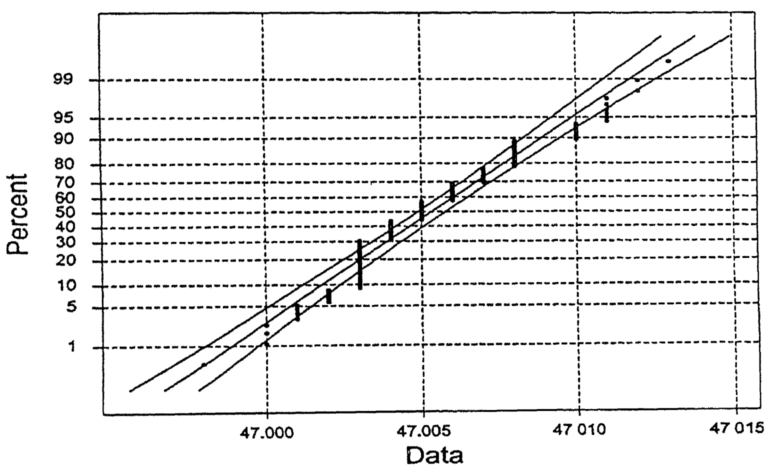


Overall Capability	
Pp	0 84
PPU	0 80
PPL	0 88
Ppk	0 80

Observed Performance		Exp "Within" Performance		Exp "Overall" Performance	
PPM < LSL	0 00	PPM < LSL	457 58	PPM < LSL	4162 77
PPM > USL	6666 67	PPM > USL	1264 92	PPM > USL	8124 20
PPM Total	6666 67	PPM Total	1722 49	PPM Total	12286 96

PROBABILITY PLOT FOR BORE DIA

ML Estimates - 95% CI



ML Estimates

Mean	47 0053
StDev	0 0027628

Goodness of Fit

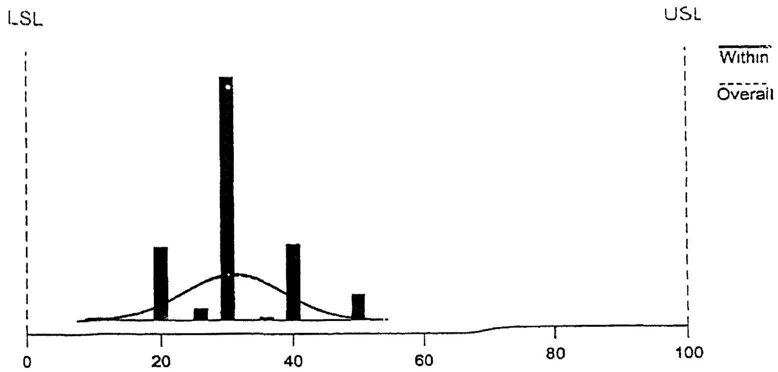
AD*	2 629

Fig. B-1: Capability analysis and probability plot for bore diameter

Process Capability Analysis for Face runout

Process Data	
USL	100 000
Target	*
LSL	0 000
Mean	31.033
Sample N	150
StDev (Within)	7 51007
StDev (Overall)	7 81296

Potential (Within) Capability	
Cp	2 22
CPU	3 06
CPL	1 38
Cpk	1 38
Cpm	*



Overall Capability	
Pp	2 13
PPU	2 94
PPL	1 32
Ppk	1.32

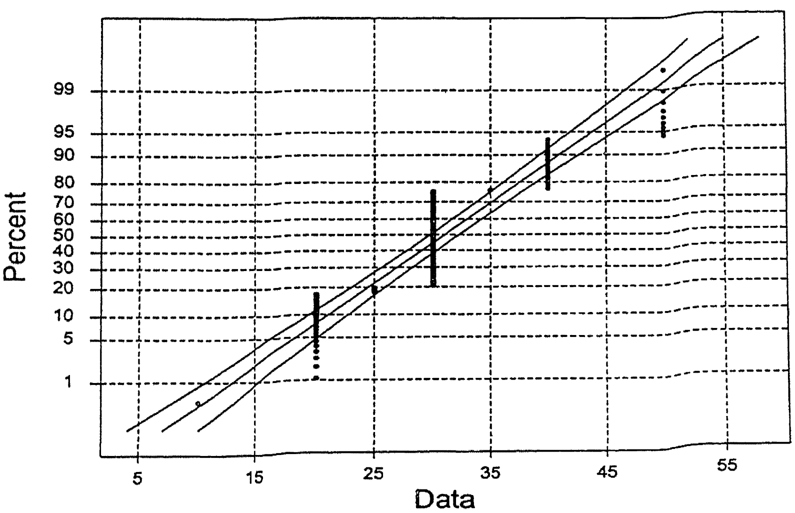
Observed Performance	
PPM < LSL	0 00
PPM > USL	0 00
PPM Total	0 00

Exp "Within" Performance	
PPM < LSL	17 96
PPM > USL	0 00
PPM Total	17 96

Exp "Overall" Performance	
PPM < LSL	35 63
PPM > USL	0 00
PPM Total	35 63

Normal Probability Plot for Face runout

ML Estimates - 95% CI



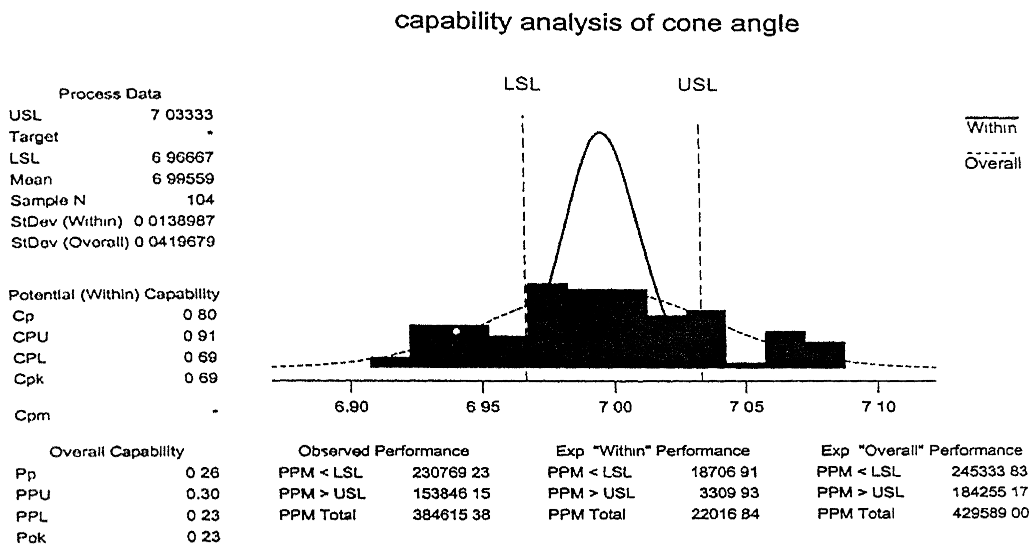
ML Estimates

Mean	31 0333
StDev	7.77382

Goodness of Fit

AD*	11 54

Fig. B-2: Capability analysis and probability plot for face runout



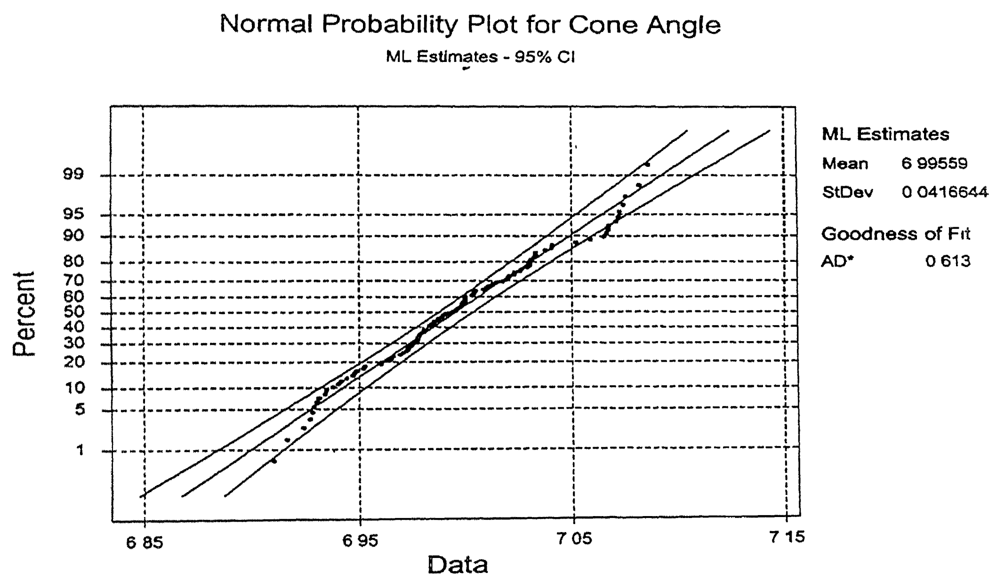
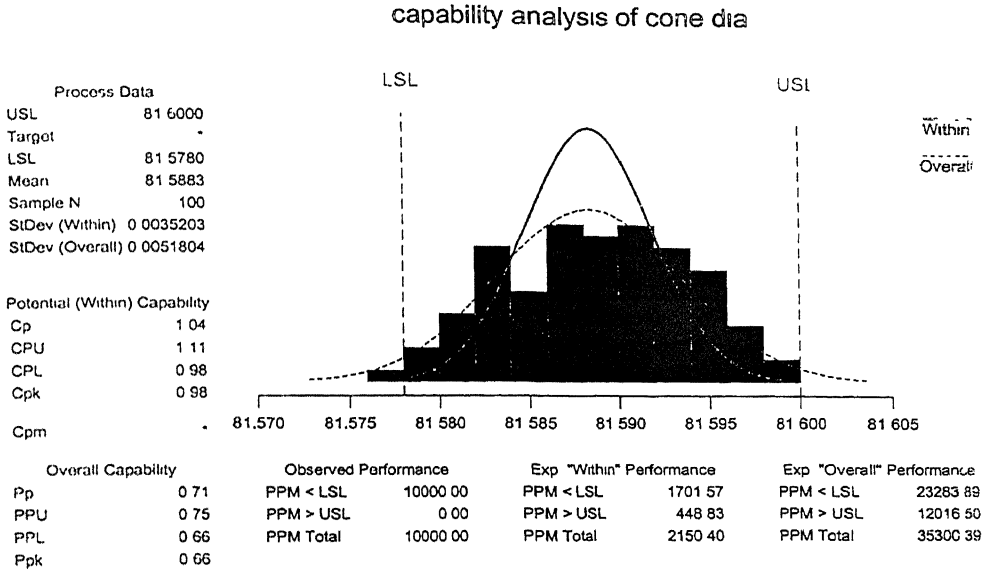


Fig. B-3: Capability analysis and probability plot for cone angle



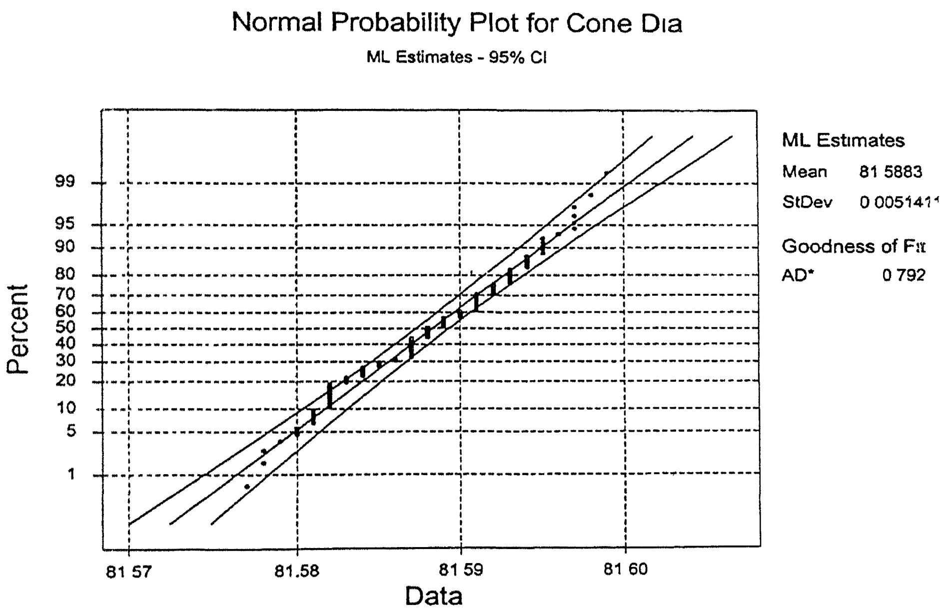


Fig. B-4: Capability analysis and probability plot for cone diameter

APPENDIX C

Calculations for control chart (Demerit system)

Since the weight of the Major Mechanical or Major Trim is 5 and for Minor Mechanical or Minor Trim is 2 hence the total defects can be classified into two main classes

1. Major defects (Weight $\mathbf{w}_{major}$ = **5**)
2. Minor defects (Weight $\mathbf{w}_{minor}$ = **5**)

Total number of major defects collected from the check sheet for **n= 171** vehicles is

$\mathbf{d}_{major}$ = **189** , hence average number of major defects/unit $\mathbf{u}_{major}$ = **189/171 = 1.11**

Total number of minor defects collected from the check sheet for **n= 171** vehicles is

$\mathbf{d}_{minor}$ = **644** , hence average number of minor defects/unit $\mathbf{u}_{minor}$ = **644/171 = 3.77**

Thus the weighted **u** is

$$u = w_{major} * u_{major} + w_{minor} * u_{minor}$$

$$= 5*1.11 + 2*3.77 = 13.06$$

And the weighted σ is

$$\sigma = [(w^2_{major} * u_{major} + w^2_{minor} * u_{minor}) / n]^{1/2}$$

$$= [(25*1.11 + 4*3.77)/ 171]^{1/2}$$

$$= 0.5$$

The Centre Line = u = 13.06

Upper Control Limit (UCL) = u + 3σ **= 13.06 + 3*0.5 = 14.56**

Lower Control Limit (UCL) = u + 3σ **= 13.06 + 3*0.5 = 11.56**